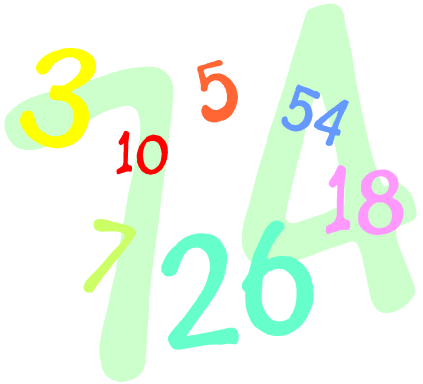
Part 1 .0
Statistics 101



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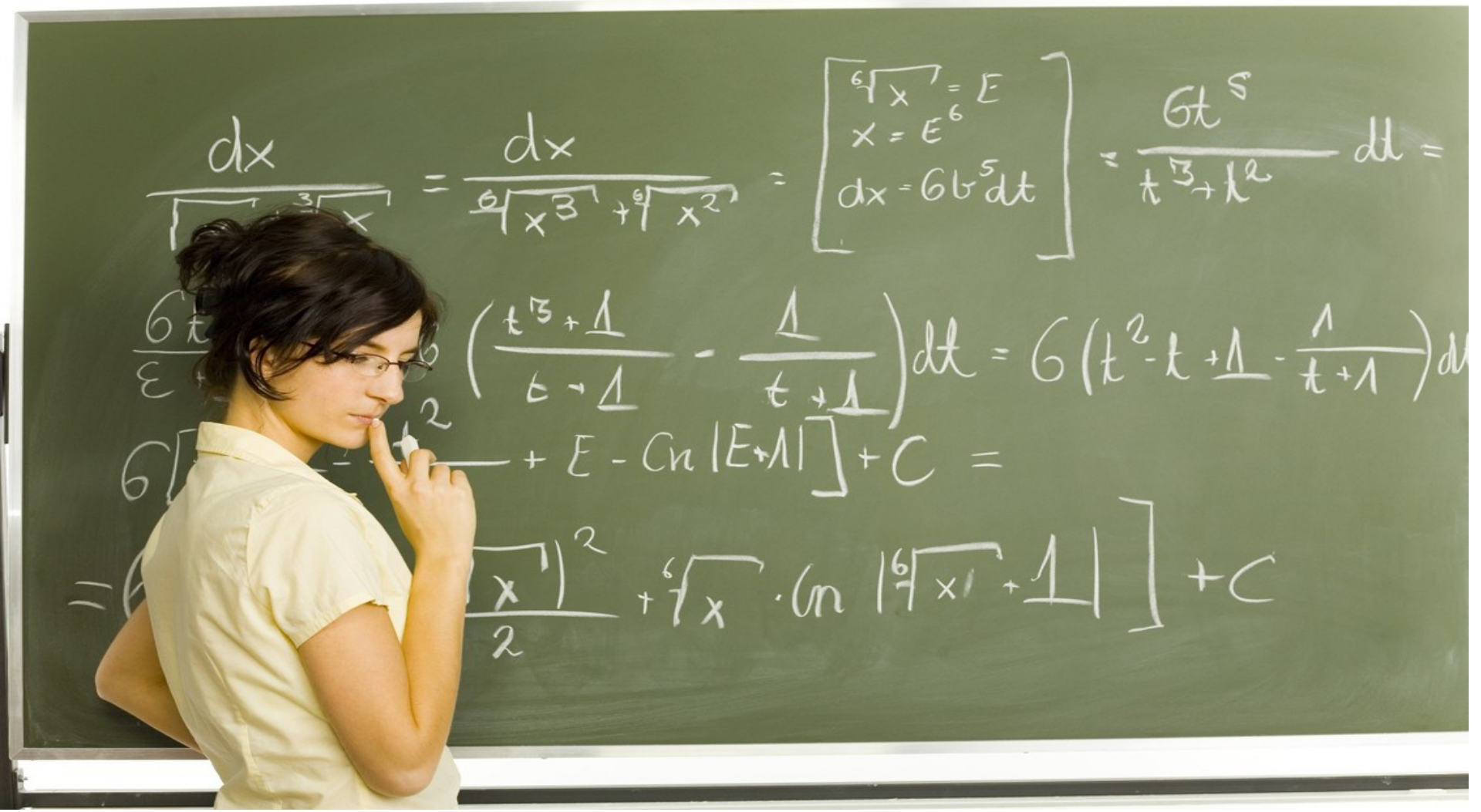
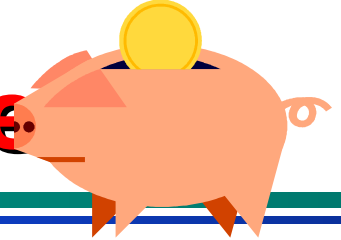
Overview & Objectives

- Introduce some fundamental statistical concepts with emphasis on interpreting results.
- Address common data evaluation problems observed during independent technical reviews.
- Hands-on experience using some free statistical software from EPA.
- Introduce statistical trend analyses (e.g., to support Five Year Reviews).

What will NOT be done



Free Statistics Guidance



- USACE EM 1110-1-4014, *Environmental Statistics,* 31 Jan. 2008.

  http://www.usace.army.mil/publications/eng-manuals

- EPA QA/G-9S, *Data Quality Assessment: Statistical Method for Practitioners,* Feb. 2006.

  http://www.epa.gov/quality/qa_docs.html

- USGS, *Statistical Methods in Water Resources,* D. R. Helsel and R.M. Hirsch, Sept. 2002.

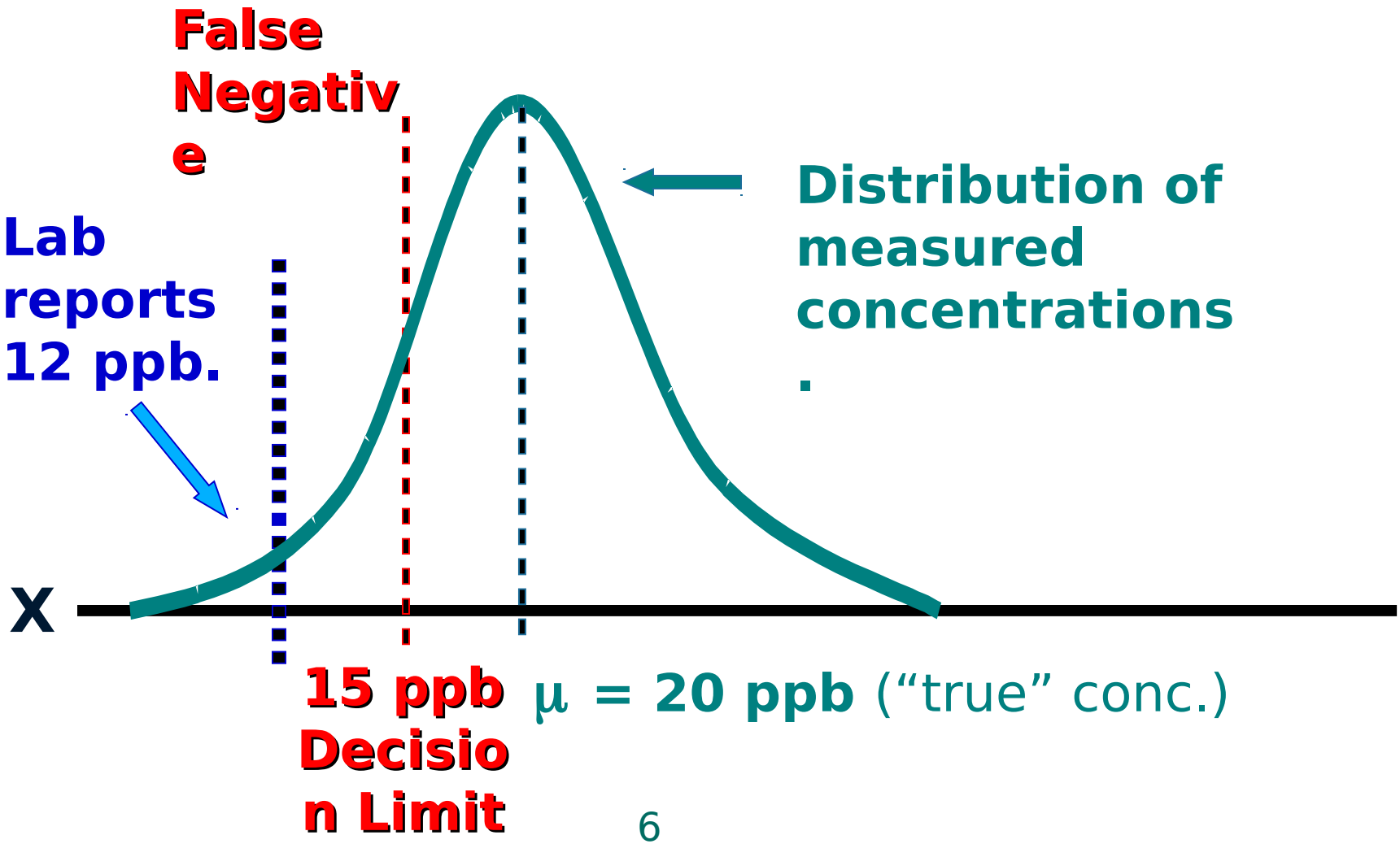
  http://www.epa.gov/region09/qa/pdfs/statguide.pdf

Why is statistics important?

- Project objective: Determine if conc. of lead (Pb) in groundwater (GW) $X < 15$ ppb.
- Collect sample & analyze at lab: $X = 12$ ppb.
- As 12 ppb < 15 ppb, conclude GW is "clean."

Conclusion is not necessarily valid

Measured Value ≠ "True" Value



Statistics Quantifies Uncertainty

- **A measurement without an estimate of its uncertainty is not useful !**

  $12 \pm 2 < 15 \rightarrow$ GW is “clean.”

  $12 \pm 5 < 15 \rightarrow$ Inconclusive result.

- Replicate measurements required to quantify uncertainty.

Population

- **Population** (“Study area” or “decision unit”): Environmental medium or set of objects of interest.

  Example: All soil enclosed within a 10 m × 10 m × 1 m (100 m^3) volume.

- **Variable, *X*:** Some characteristic or property of population of interest that will be measured.

  Example: Concentration (conc.) of Pb in 1-g aliquots of soil at study area.

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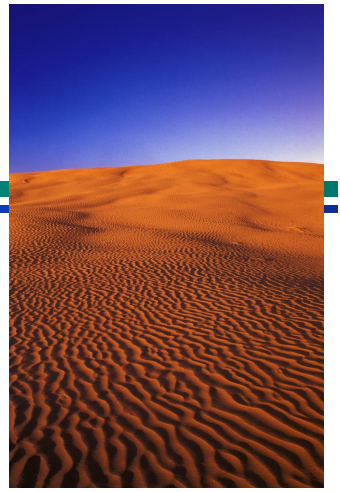


- **Population size, N:** Number objects or units in population.

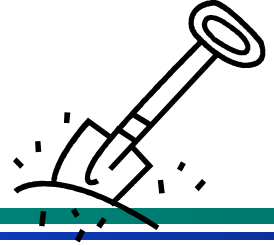
  Example: Total number of 1-g aliquots in population.
  100 m^3 soil volume $\rightarrow$ $N \approx 10^8\ cm^3 \times 1.5\ g/cm^3 \times 1$ aliquot/g $= 1.5 \times 10^8$ (150 million) aliquots.

- **Population Parameter, Θ** = "True" value of population characteristic.

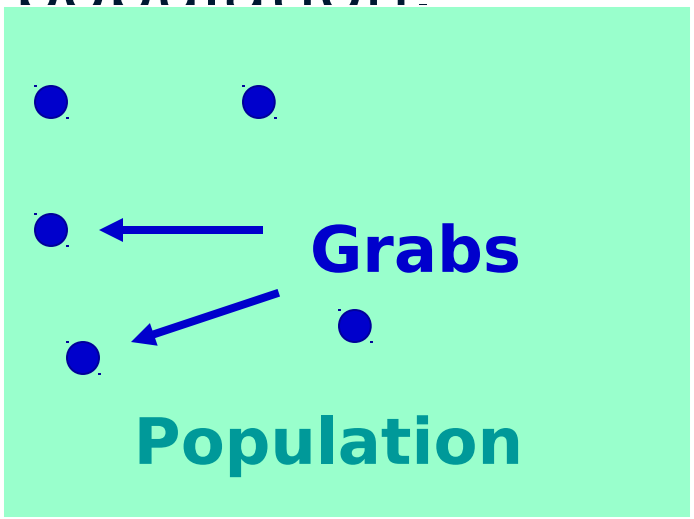
  Example: Population mean, μ

  Mean Pb conc. of all 1-g aliquots in study area.

Sample



- **Sample**: **Physically**, some (usually small) portion of population that **represents** entire population.



X = Concentration of Pb in 1-g grabs of soil from 100 m^3 study area. 5 grabs are collected.

What is the **sample**?

Set of $n = 5$ grabs is **the sample** to a statistician; the grabs are “specimens” (“samples” to chemists).

(Continued)

- **Sample**: **Mathematically**, a set of *n* measurements of some variable *X*

  $\{x_1, x_2, x_3, \ldots x_n\}$

- **Sample size, *n*** = Number of replicate measurements (taken to estimate the population parameter).

- **Sample statistic**: Estimate of the population parameter calculated from sample.

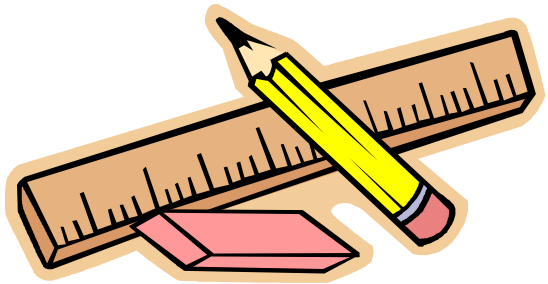
Examples of Sample Statistics

Sample mean

$$\bar{x} = (x_1 + x_2 + x_3 + \ldots + x_n) / n$$

estimates **population mean**

$$\mu = (x_1 + x_2 + x_3 + \ldots + x_N) / N$$



Examples of Sample Statistics

Sample variance

$$s^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}$$

Why are the two formulas for the variance different?

estimates **population variance**

$$\sigma^2 = \frac{\sum_{i=1}^{N} (x_i - \mu)^2}{N}$$

Bias

The quantity (also called the sample variance)

$$s^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}$$

is a **biased estimator** of σ^2. The **expectation value** (mean) of statistic s, $E(s) = \sigma^2$ but

$$E(s^2) = \frac{n-1}{n}\sigma^2 < \sigma^2$$

Expectation Value

$$E(X) = \mu = \begin{cases} \sum_i f(X_i) X_i & X = \text{Discrete variable} \\ \int f(X)\, X\, dX & X = \text{Continuous variable} \end{cases}$$

$X \rightarrow g(X)$

$f(X)$ = probability of X. Can also find E{g(X)}.

Examples:

Discrete: $X = 0, 1$; $f(0) = f(1) = 0.5$.

$E(X) = [f(0) \times 0] + [f(1) \times 1] = 0.5$

Continuous: X = norma

$$f(X) = \frac{e^{-\frac{1}{2}\left[\frac{X-\mu}{\sigma}\right]^2}}{\sigma\sqrt{2\pi}}$$

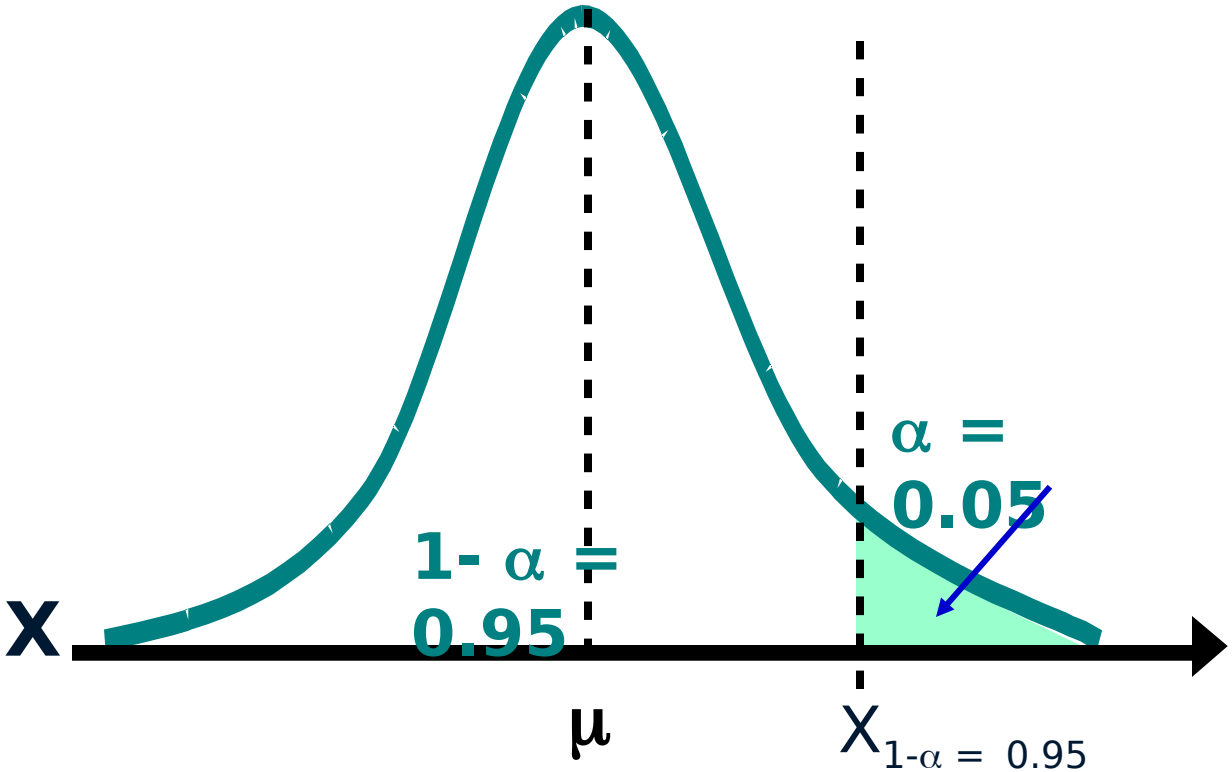
Notation

Population Parameter	Sample Statistic
μ, μ_X (Mean of X)	$\bar{x}$
σ, σ_X (Standard deviation of X)	s, s_X
$X_{0.95}$ (95th percentile of X)	$x_{0.95}$

Percentiles

$X_{0.95}$ = Value equal to or greater than 95% of population: $P(X \leq X_{0.95}) = 0.95$.

$X_{0.95} = \mu + 1.64\ \sigma$ - Population percentile if X is normal.



Note: If $\mu = 0$ & $\sigma = 1$, $X_{0.95} = \boldsymbol{Z_{0.95}} = 1.64$, 95th percentile of **standard normal distribution**. Different values of $Z_{1-\alpha}$ (e.g., $\alpha = 0.05$) listed in tables.

Sample Percentile

- If $X_{0.95} = \mu + 1.64\ \sigma$ what is the 95th sample percentile when $n = 20$?

To find the 95th sample percentile order the sample results

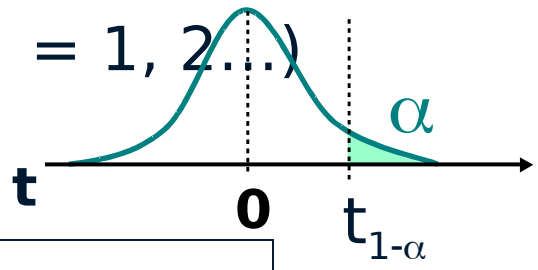
$$\boldsymbol{X_{(1)} < X_{(2)} < X_{(3)} \ldots < X_{(n)}}$$

$$\boldsymbol{X_{0.95} = X_{(n \times 0.95)} = X_{(19)}} \quad (19/20 = 0.95)$$

Parametric estimate of $X_{0.95} = \bar{x} + 1.64\ s$

Table of Student's t values, $t_{1-\alpha, \varphi}$

(1- α)100th percentiles of Student's t distribution with φ (phi) degrees of freedom (φ = 1, 2…)



φ	α		
	0.10	**0.05**	**0. 025**
1	3.08	6.31	12.71
2	1.89	2.92	4.30
3	1.64	2.35	3.18
4	1.53	2.13	2.78
…			
∞	1.28	1.64	1.96 ← $Z_{1-\alpha}$

Often

$\varphi = n - 1$

n = sample size

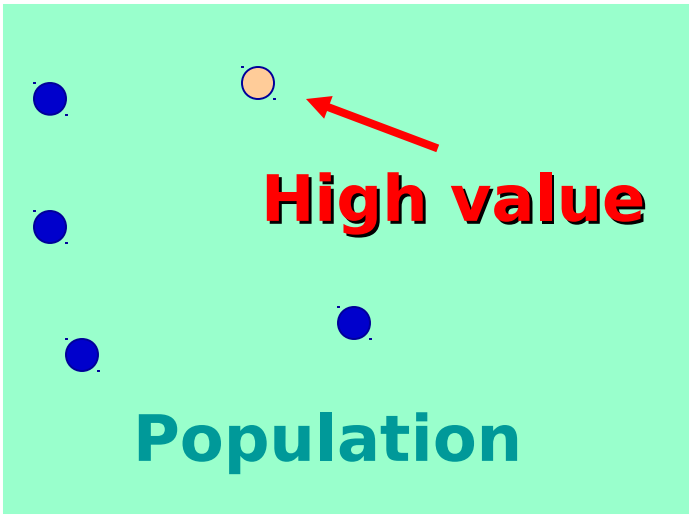
Note: If $\varphi > 20$

$t_{1-\alpha, \varphi} \approx Z_{1-\alpha}$

Part 1.1
Hot spots and Sampling Designs

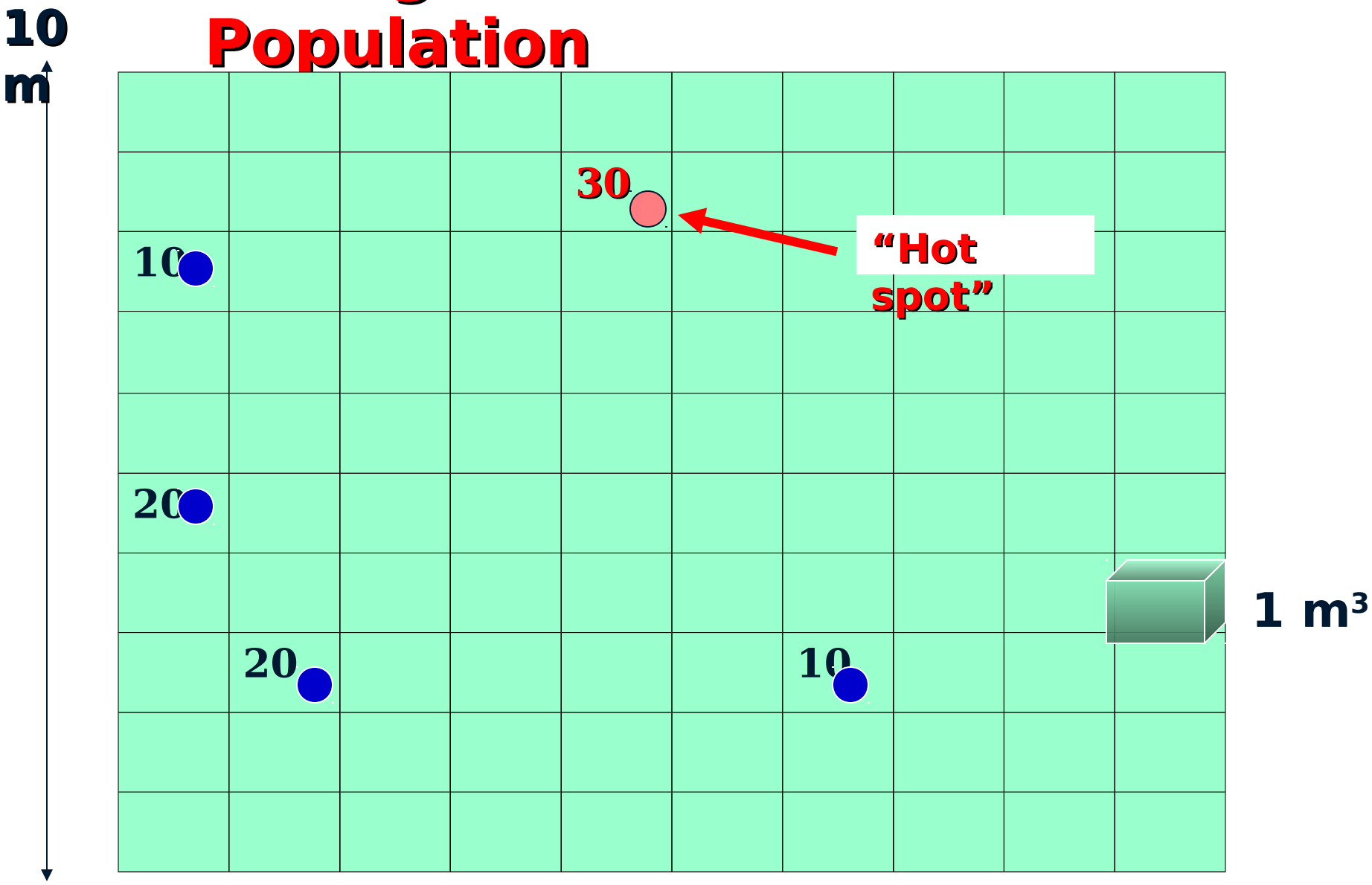
Hot Spot Paranoia

- Several grabs (e.g., n = 5) are randomly collected but one grab exceeds a risk-based screening limit. Is the location at which the grab was collected a “hot spot” ?

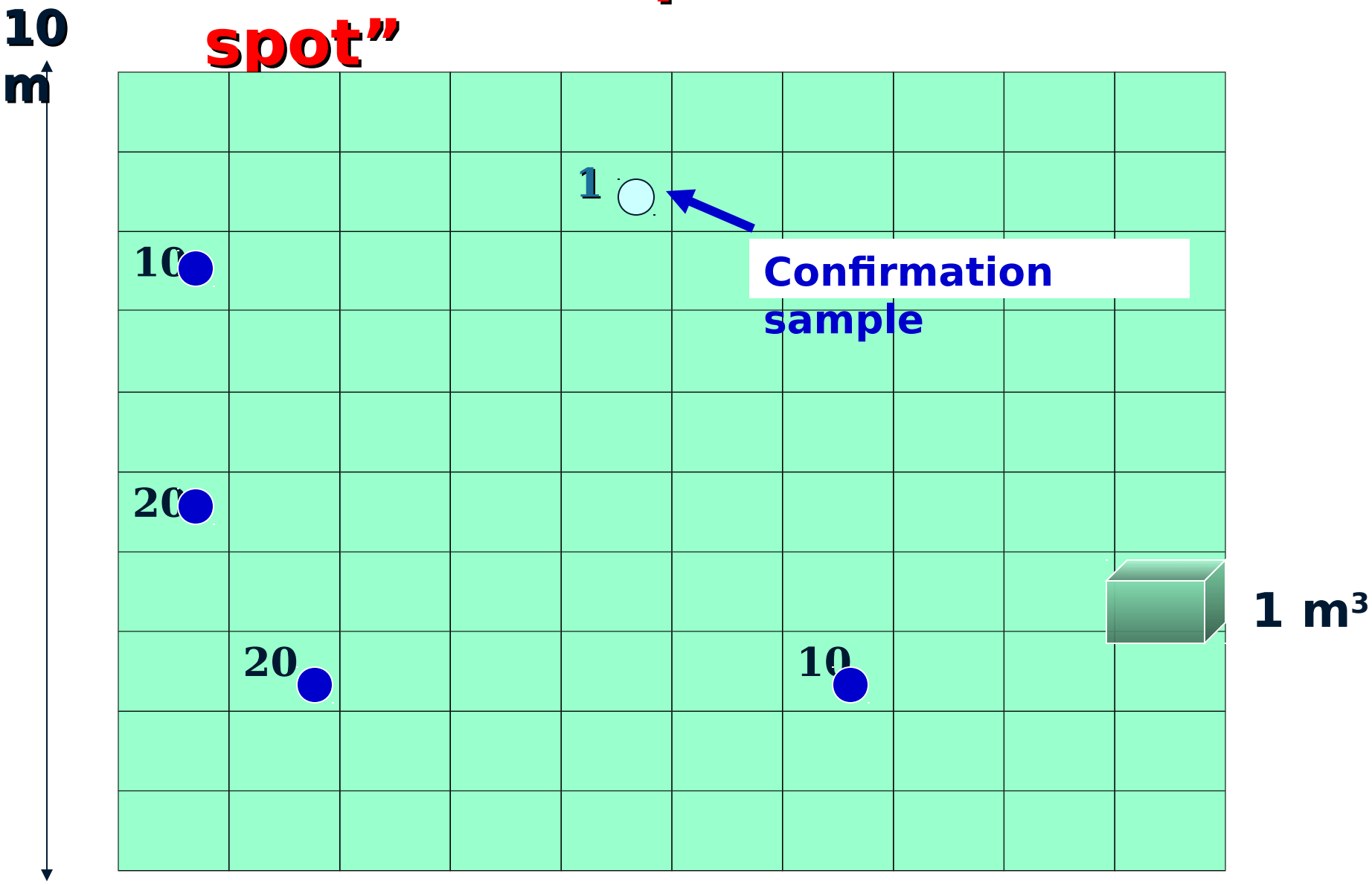


Probably not.
The set of grabs is the sample; an individual grab does not represent anything (i.e., some volume of soil). High value likely owing to random variability.

Enlarged View of Population



After Cleanup of “hot spot”



Before Cleanup

μ = 20, Action Level (AL) = 25, 33% of site > AL

10 m

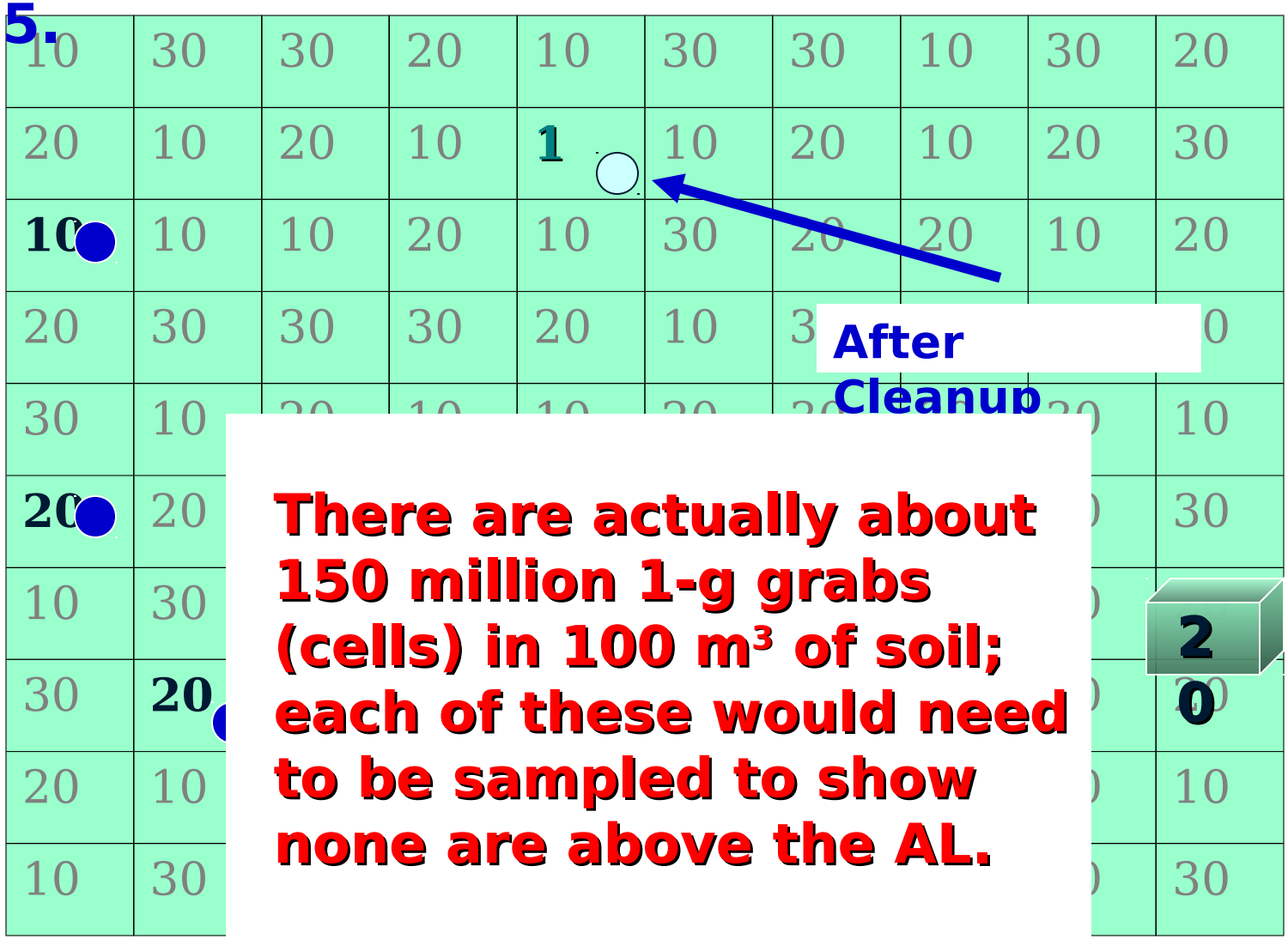
10	30	30	20	10	30	30	10	30	20
20	10	20	10	30	10	20	10	20	30
10	10	10	20	10	30	20	20	10	20
20	30	30	30	20	10	30	30	10	30
30	10	20	10	10	20	30	30	30	10
10	20	30	30	20	20	10	10	20	30
10	30	10	30	30	20	30	20	10	20
30	20	20	20	10	30	10	20	20	20
20	10	30	10	30	20	20	30	30	10
10	30	10	20	20	10	30	10	20	30

"Hot spot"

1 m³

After Cleanup

32% of site > AL. $\mu = 20 \rightarrow \mu = 19.7 < AL = 25$.



There are actually about 150 million 1-g grabs (cells) in 100 m³ of soil; each of these would need to be sampled to show none are above the AL.

Defining Hot Spots

Mass = Concentration × Volume

- Any definition of a hot spot that does not address the **concentration and volume** (size) of the hot spot relative to the population (exposure unit) is not scientifically defensible.

Most definitions of hot spots are either incomplete or invalid ! *

- Oregon:

  Any conc. 10 – 100 × acceptable human or ecological risk.

- Washington:

  …small patches of higher level contamination…

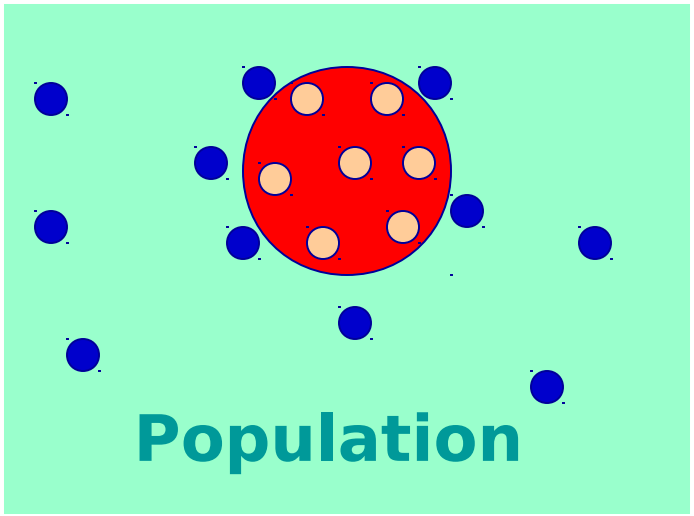
- New Hampshire

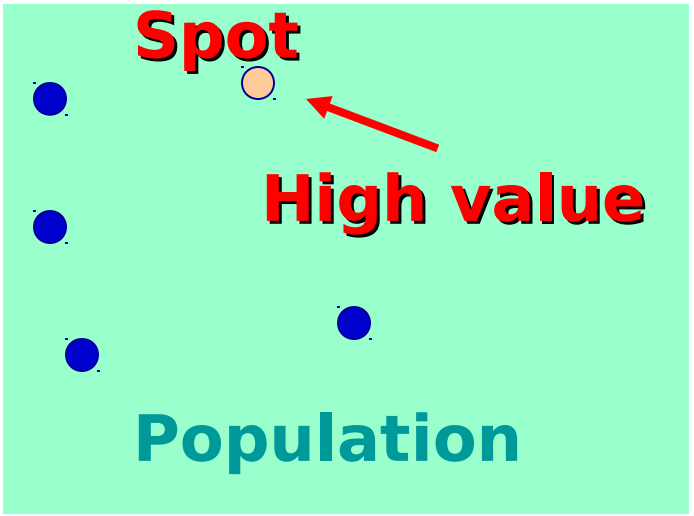
  …any region that exceeds some threshold concentration…

  * *Use of Risk Assessment in Management of Contaminated Sites*, Interstate Technology & Regulatory Council, 03/08

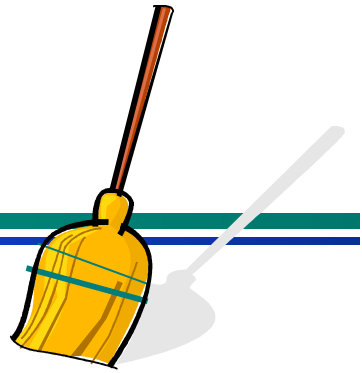
Hot Spots

- "Hot spot" must have a well-defined **volume**. The size must be significant relative to that of the entire study area. The number of grabs must be large enough to determine the spatial boundaries and quantify the contaminant **concentration**.

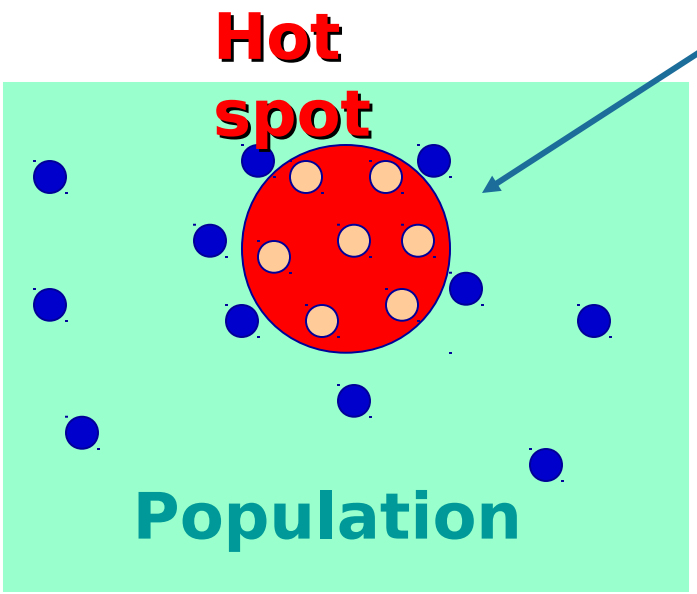




Is cleanup required?



AL (action level) = 10, $\bar{x}_{\text{Hot Spot}} = 100$

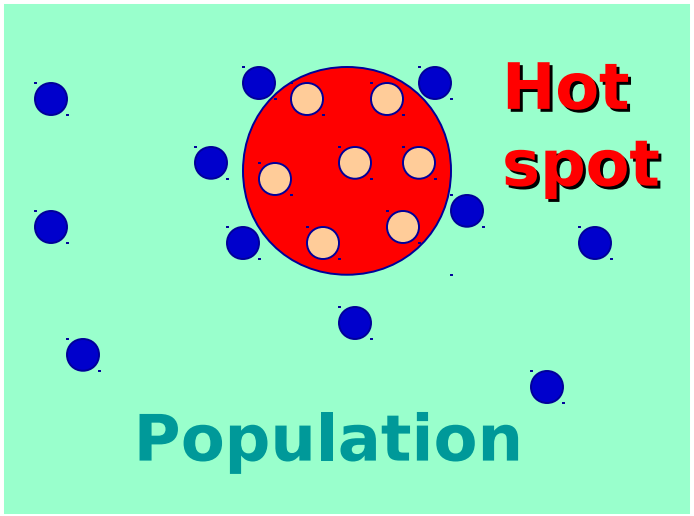


Not necessarily!

Need to know (i) conc. in “clean” area (ii) size of hot spot relative to that of study area.

Calculating a weighted mean

$$\bar{x}_{Site} = w_{Hot\ Spot}\,\bar{x}_{Hot\ Spot} + w_{Clean}\,\bar{x}_{clean}$$



$\bar{x}_{Site}$ = Weighted site sample mean

w = Weighting factor

$w_{Hot\ Spot} + w_{Clean} = 1$

$w_{Hot\ Spot}$ = "Hot spot" area / Total site area

w_{Clean} = "Clean" area / Total site area

Determining if cleanup is needed

AL (action level) = 10, $\bar{x}_{\text{Hot Spot}} = 100$, $\bar{x}_{\text{clean}} = 1$,

$w_{\text{Hot Spot}} = 0.05$, $w_{\text{Clean}} = 1 - w_{\text{Hot Spot}} = 0.95$

$$\bar{x}_{\text{Site}} = w_{\text{Hot Spot}}\bar{x}_{\text{Hot Spot}} + w_{\text{Clean}}\bar{x}_{\text{clean}}$$

$$= (0.05 \times 100) + (0.95 \times 1) = \mathbf{5.95 < 10}$$

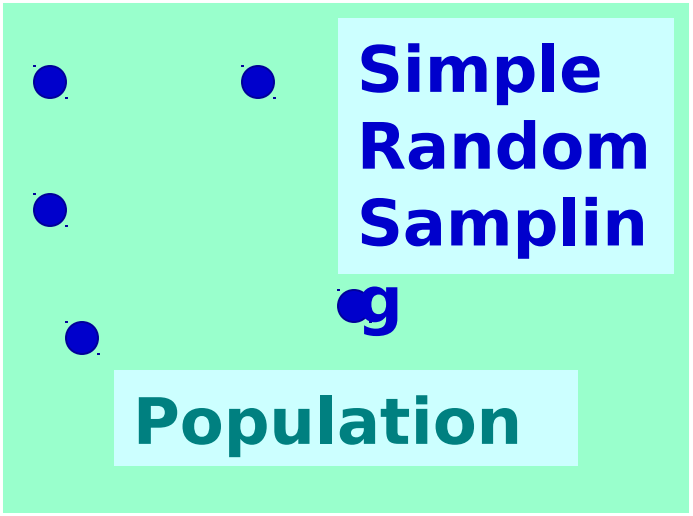
Cleanup not required! Hot spot is too small for risk to be unacceptable for entire study area (exposure unit).

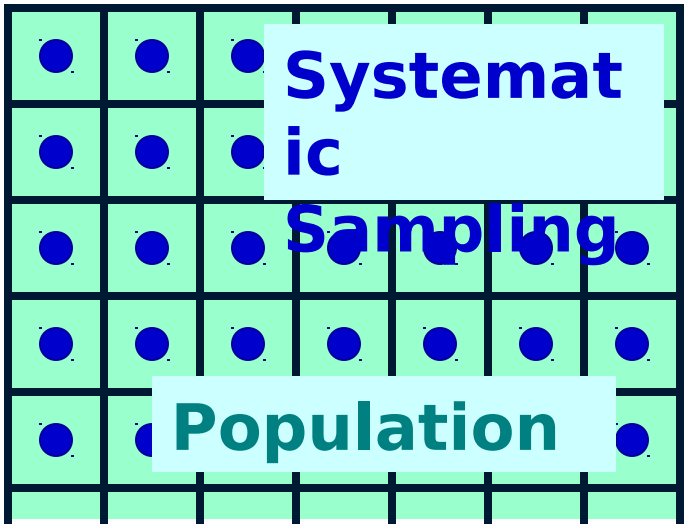
Part 1.2
Obtaining Representative Samples

Samples need to be representative

- Sample statistics are not meaningful if sample is not physically **representative** of population.
- “Representativeness” largely depends on sampling design.
- A statistically-based sampling design (e.g., simple **random** or systematic/grid sampling) is needed.
- **Random** – Every sample has an equal opportunity of being selected.

Statistical Sampling Designs

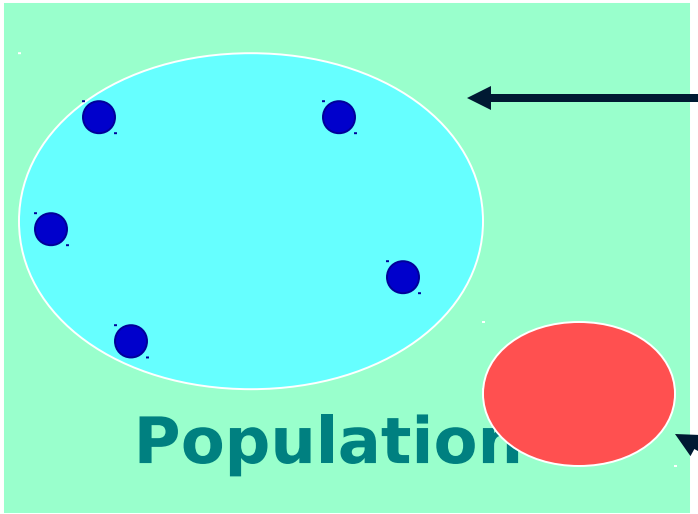




- EPA QA/G-5S is a good reference.
- Composites or a large number of grabs typically needed for a representative sample because of large heterogeneity.

How to NOT take a representative sample

- Take a **small number of biased grabs** using “professional judgment” from a very heterogeneous medium (e.g., soils and sediment).



Grabs taken in “stained” soil only.
5-grabs do not represent entire population but possibly stained area only.

Hot spot area with no visible staining.

Biased Sampling

- Reliable inferences about a study area cannot be made from biased sampling (the sample is not necessarily representative of the population).

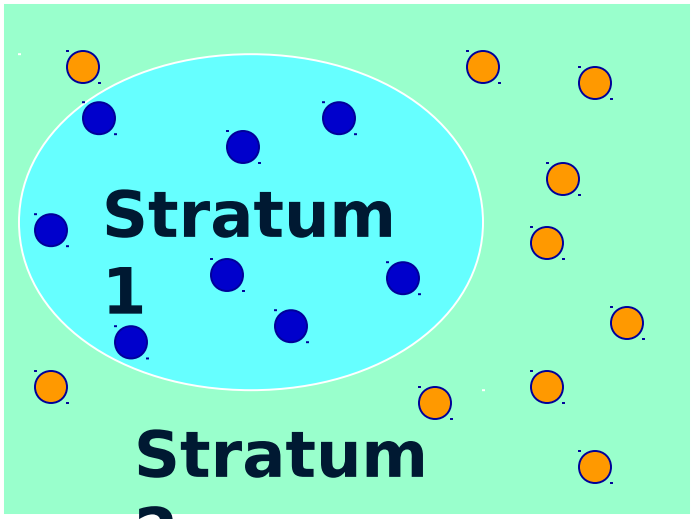
EPA QA/G-5S

Judgmental sampling *does* ***not*** *allow the level of confidence (uncertainty)…to be accurately quantified. In addition, judgmental sampling limits the inferences made to the units actually analyzed, and extrapolation from those units to the overall population…is subject to* ***unknown*** *selection* ***bias****.*

Taking a more representative sample

- Stratify the population and do random sampling in each stratum.

$$\bar{x} = w_1 \bar{x}_1 + w_2 \bar{x}_2$$



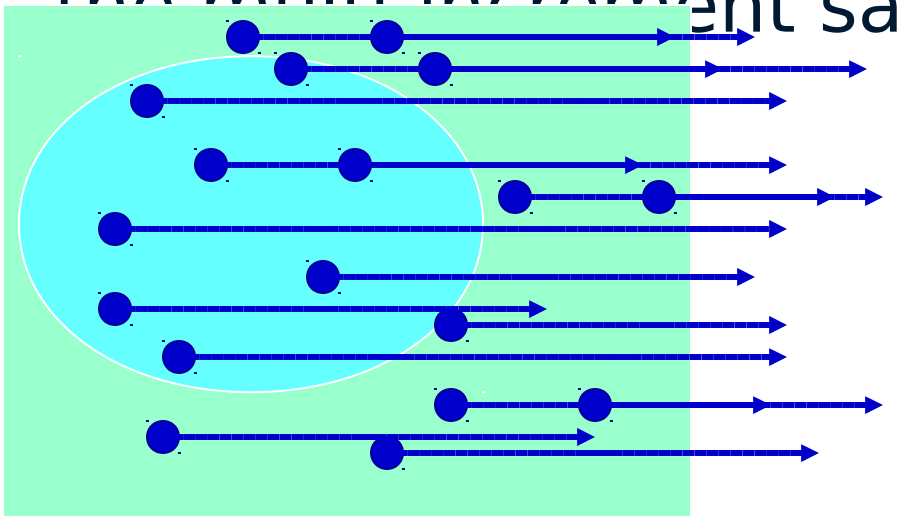
Stratified Random Sampling

Stratum 1: Stained area

Stratum 2: Remaining portion of population

(Continued)

- Take composites using large number of grabs. Each composite represents entire population (because grabs “cover” population in unbiased manner). Basis of the multi-increment sampling.



Composite or Multi-increment Sampling

Composite → $\bar{x}$

Population

Part 1.3
Statistical Intervals

Confidence Interval (CI) (of population parameter)

- Interval in which <u>population parameter</u>, Θ (theta), falls within some level of confidence (probability). End points of intervals are **confidence limits**.
  - **One-sided CI:** $\Theta \leq$ UCL or LCL $\leq \Theta$
  - **Two sided CI**: LCL $\leq \Theta \leq$ UCL

LCL - Lower Confidence Limit

UCL - Upper Confidence Limit

Upper Confidence Limit of the Population Mean, μ

- 95% upper confidence limit (UCL) of the population mean (contaminant concentration) commonly used for risk assessments.

Probability $\mu \leq$ UCL is 95%: P($\mu \leq$ UCL) = 0.95

(Continued)

- Method to calculate UCL depends on nature of distribution (e.g., normal vs. lognormal), sample size and proportion of non-detects. Use ProUCL (Version 4) to calculate.

- If X is normal and results are all detects,

$$95\%\ \text{UCL} = \bar{x} + t_{n-1,\,0.95}\, s / n^{1/2}$$

Types of Statistical Limits (Normal Data)

- **Confidence**: Interval to contain mean at (1-α) CL.

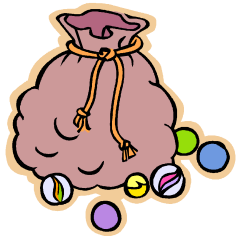
$$UCL = \bar{x} + t_{1-\alpha, n-1} / n^{1/2} \; s$$

- **Prediction**: Interval to contain a set of *k* future observations at (1-α) confidence level (CL) .

$$UPL = \bar{x} + t_{1-\alpha/k, n-1} (1 + 1/n)^{1/2} s$$

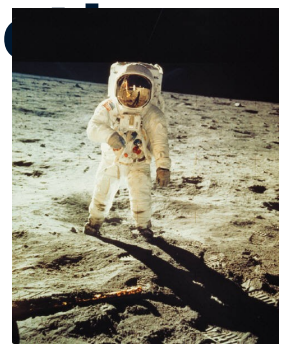
- **Tolerance**: Interval to contain a proportion *p* of future observations at (1-α) CL.

$$UTL = \bar{x} + g'_{1-\alpha, p, n} \; s$$



Statistical Intervals Exercise

- You are an astronaut calculating the amount of fuel, *Y*, required to take a round trip to the moon. Based on 20 prior moon trips, the round-trip fuel required is normally distributed ($\bar{x} = 10$, $s = 2$). Another 20 trips are planned. You would like to be 99% confident that there will be enough fuel for each trip. Would you calculate an **upper confidence limit of the mean**, **predi limit** or **tolerance limit**?



Solution

$\bar{x} = 10,\ s = 2,\ n = 20,\ p = 0.99,\ k = 20,\ \alpha = 0.01,\ 1 - \alpha = 0.99,\ 1 - \alpha/k = 0.9995$

- **Upper Confidence Limit:** (p. K-6 & B-43 of Stat EM)

$$99\%\ \text{UCL} = \bar{x} + t/\sqrt{n} \times s = 10 + 2.54/\sqrt{20} \times 2 = 11.14$$

- **Upper Prediction Limit:** (p. K-15 & B-43 of Stat EM)

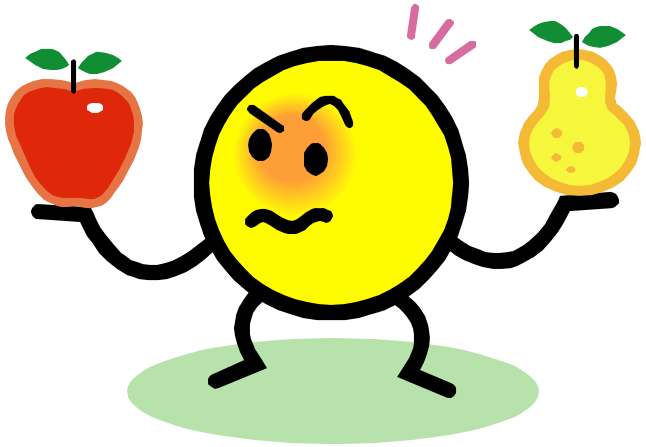
$$99\%\ \text{UPL} = \bar{x} + t\sqrt{1 + 1/n} \times s = 10 + 3.88 \times \sqrt{1 + 1/20} \times 2 = 17.95$$

✓

- **Upper Tolerance Limit:** (p. K-10 & B-26 of Stat EM)

$$99\%\ \text{UTL} = \bar{x} + g' \times s = 10 + 3.83 \times 2 = 17.66$$

Part 1.4
UCLs versus Maximums



TRUE or FALSE ?

- UCLs are often not needed for a Site Investigation (SI) because it is conservative to do biased sampling and compare the maximum detected value with the decision limit.
  - **Risk Assessment Guidance**: *The basis of the screening-level HHRA is a comparison of site media concentrations (typically, the maximum detected concentration is used) with health-based screening levels… Sampling should have been conducted in areas of suspected contamination…*

Example

- Action Level for DNT in soil = 0.75 ppm
- *n* = 5 “biased” sample results (ppm):

  0.51, **0.61 (max)**, 0.12, 0.16, 0.39

- Conclusion: It is conservative to eliminate contaminant during screening for SI, as the maximum **0.61 ppm < 0.75 ppm**.

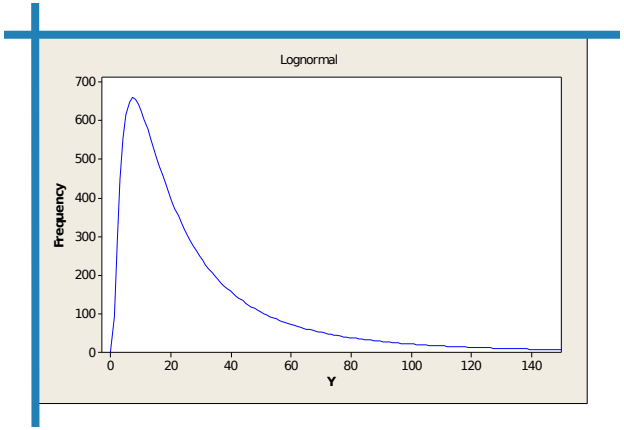
True or False ?

FALSE

- Values (0.51, 0.61, 0.12, 0.16, 0.39) are first 5 points randomly taken from lognormal distribution with $\sigma = 2$ and $\mu = 1.1$.

- 0.61 (maximum) < 0.75 (AL) →

  Wrong Conclusion, as $\mu = 1.1 > AL = 0.75$!



Why did comparing the sample max to the AL result in the wrong conclusion?

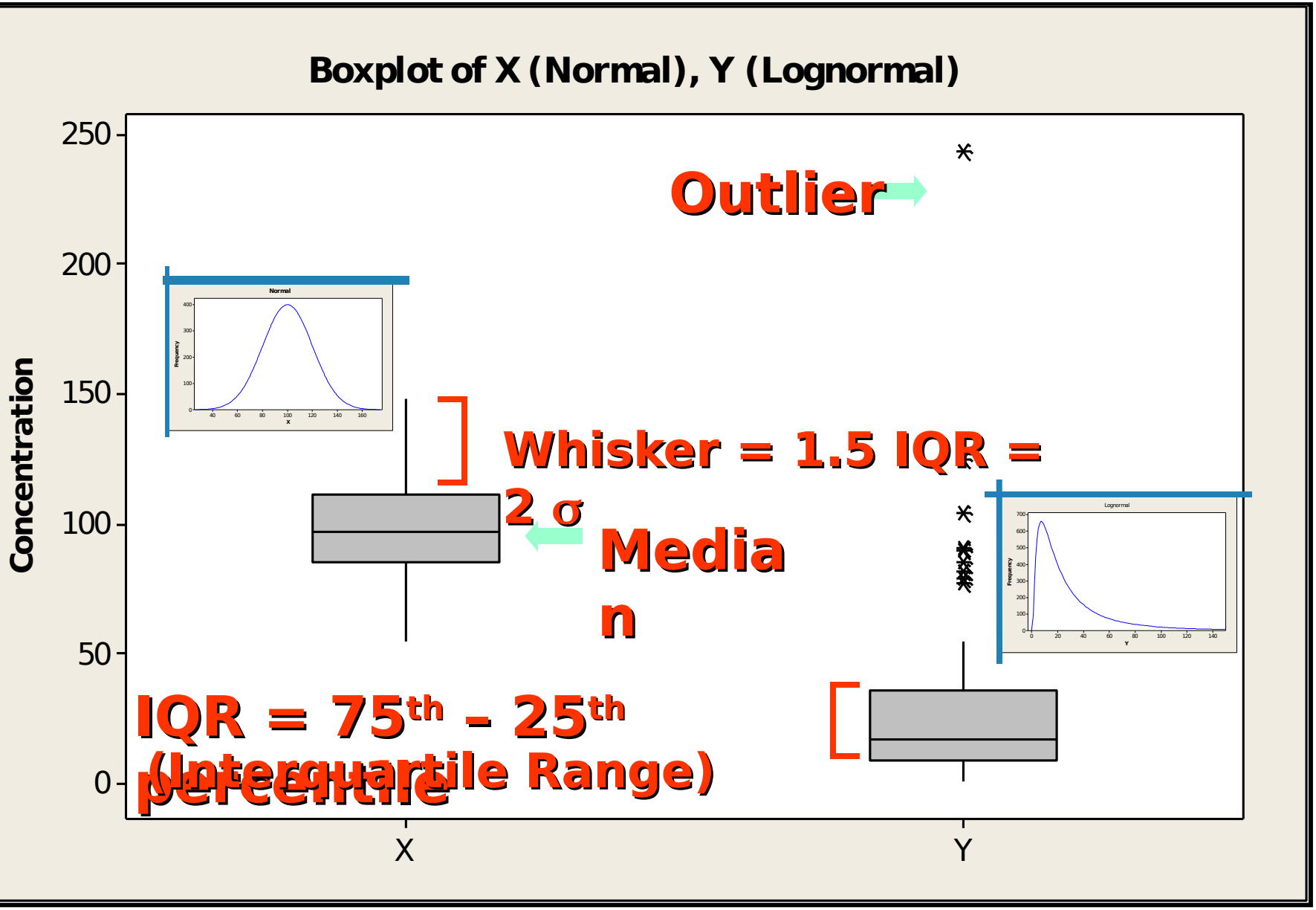
- Sample maximum (max) is a poor predictor of the population maximum
  - Population max is unknown (e.g., unless entire population is tested or is homogeneous).
- Max does not provide information about μ. Comparing sample max to AL can produce:
  - False negatives (FNs) & false positives (FPs) when n is small (e.g., $n \leq 5$)
  - FPs when n is large.

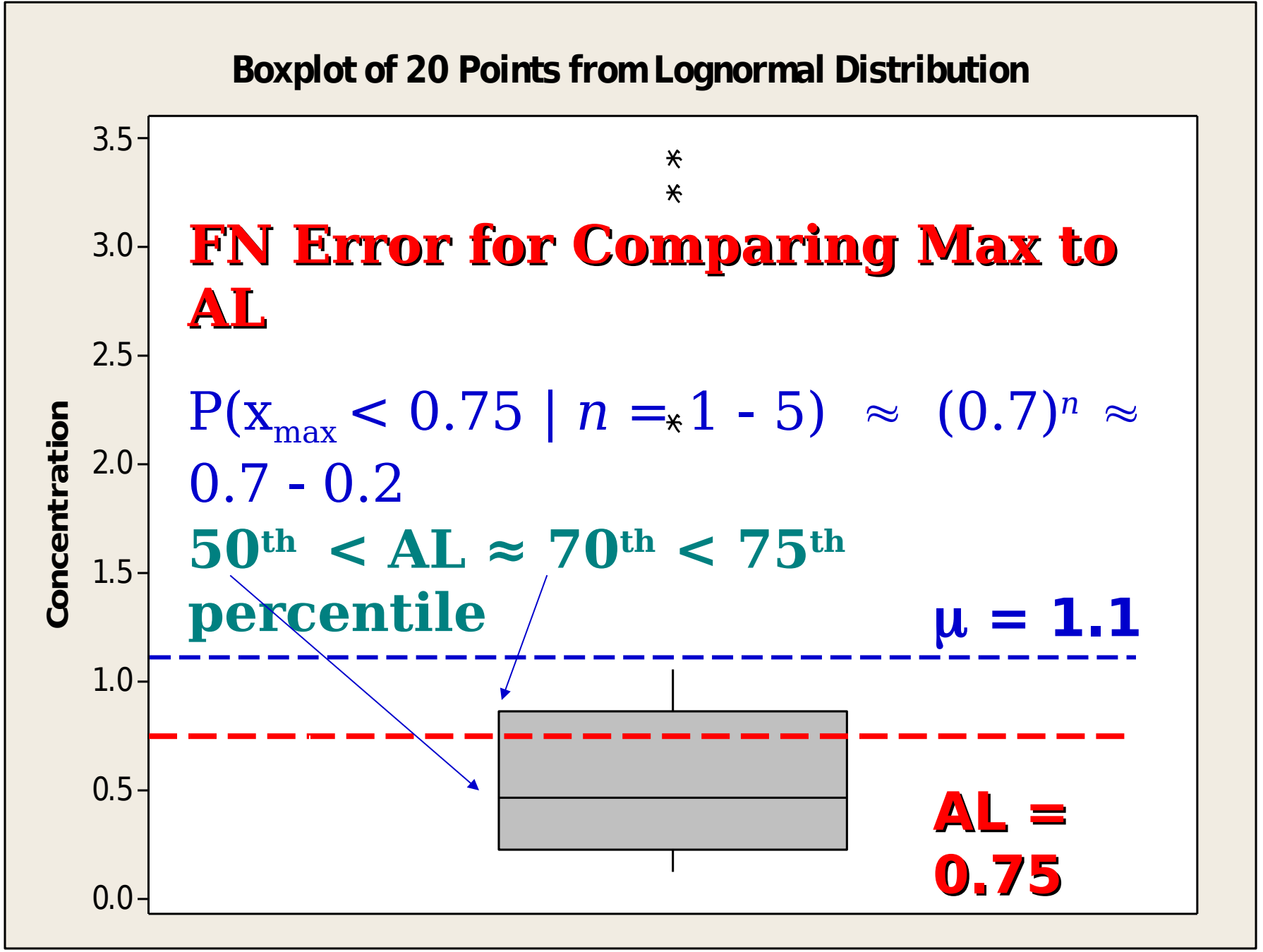
- Small *n* resulted in FN!
  - Likelihood of correct decision depends on shape (type) of the distribution, which cannot be known if *n* is small.
  - "Rule of thumb": $n \geq 15$
- Results from ProUCL using random 20 pts (from lognormal distribution with $\sigma = 2$ and $\mu = 1.1$) :

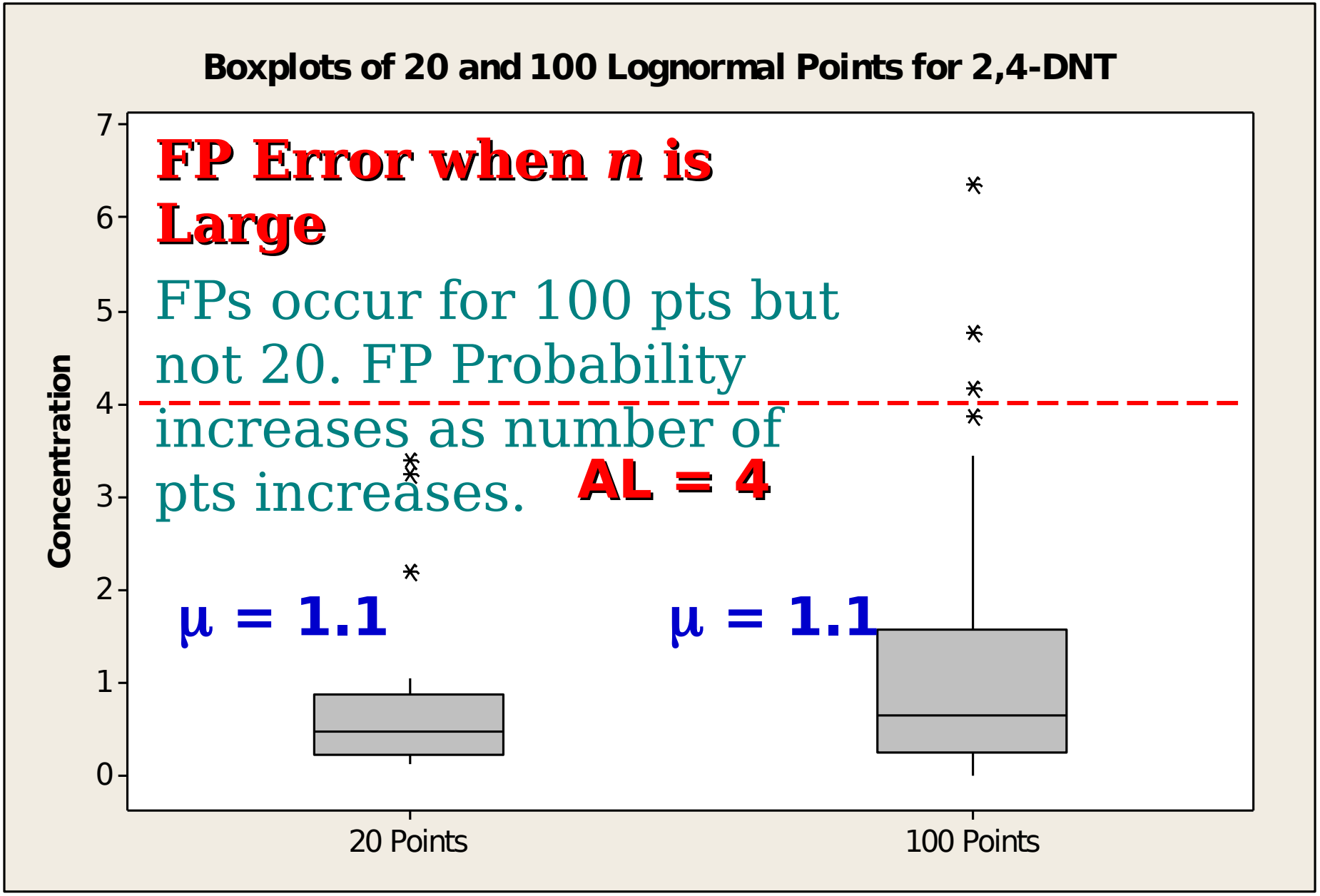
  $s = 0.98$, $\bar{x} = 0.81$, **95% UCL = 1.4**

  UCL > AL → Correct conclusion.

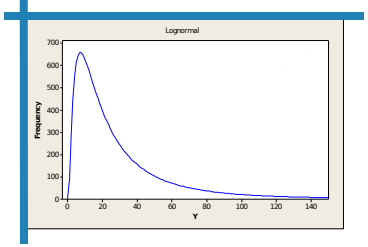
Box Plots


Boxplot of X (Normal), Y (Lognormal)
Concentration
250
200
150
100
50
0
X
Y
Outlier
Whisker = 1.5 IQR = 2 σ
Media n
IQR = 75th – 25th (Interquartile Range)
percentile
Normal
Lognormal
Frequency


Boxplot of 20 Points from Lognormal Distribution
Concentration
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
FN Error for Comparing Max to AL
P(x_max < 0.75 | n = 1 - 5) ≈ (0.7)^n ≈
0.7 - 0.2
50th < AL ≈ 70th < 75th percentile
μ = 1.1
AL = 0.75

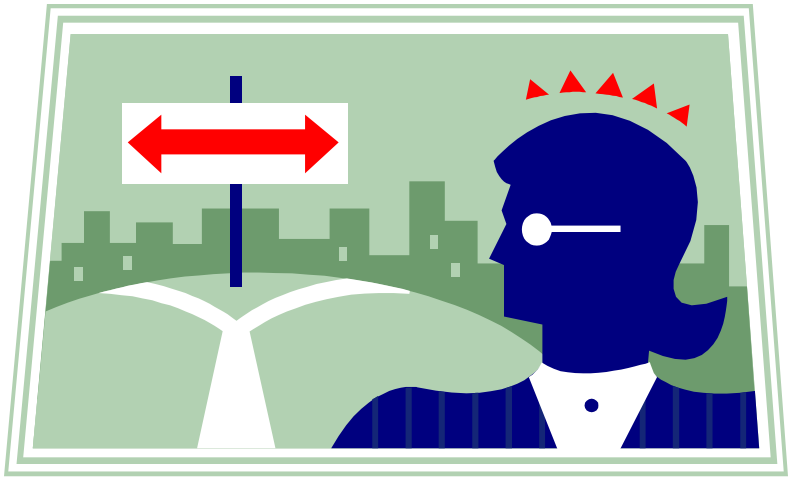

Boxplots of 20 and 100 Lognormal Points for 2,4-DNT
FP Error when n is Large
FPs occur for 100 pts but not 20. FP Probability increases as number of pts increases.
AL = 4
μ = 1.1
μ = 1.1
Concentration
0
1
2
3
4
5
6
7
20 Points
100 Points

Skewed Distributions

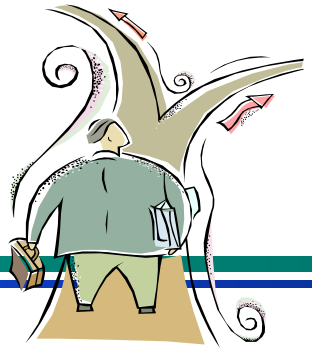


- Good estimates (e.g., of the mean) are often problematic for very skewed distributions even for moderate sample sizes (e.g., n = 20 – 30).
- Positively skewed distributions (e.g., many non-detects with a few extreme values) and large varability is indicative of a poor sampling design.
- Composite (e.g., multi-increment) samples tend to normalize distributions, produce fewer non-detects and decrease the variability.

Part 1.5
Hypothesis Tests



Hypothesis Tests



- **Null or Baseline Hypothesis, H_0**: What is initially assumed to be true. The objective is to show H_0 is false (unlikely); i.e., to "reject H_0."
  - *Statisticians try to prove the opposite (H_1) of what they initially assume is true (H_0)!*
- **Alternative (test) hypothesis, H_1**: What is proved when H_0 is rejected.
- Decisions based on binary logic – Either H_0 is true or false and H_1 is the opposite of H_0.

Examples

- Objective: Prove all apples are not red.

  H_0: All apples are red

  H_1: All apples are not red

- Objective: Prove (population mean) $\mu > 10$

  H_0: $\mu \leq 10$

  H_1: $\mu > 10$

Interpreting Hypothesis Tests

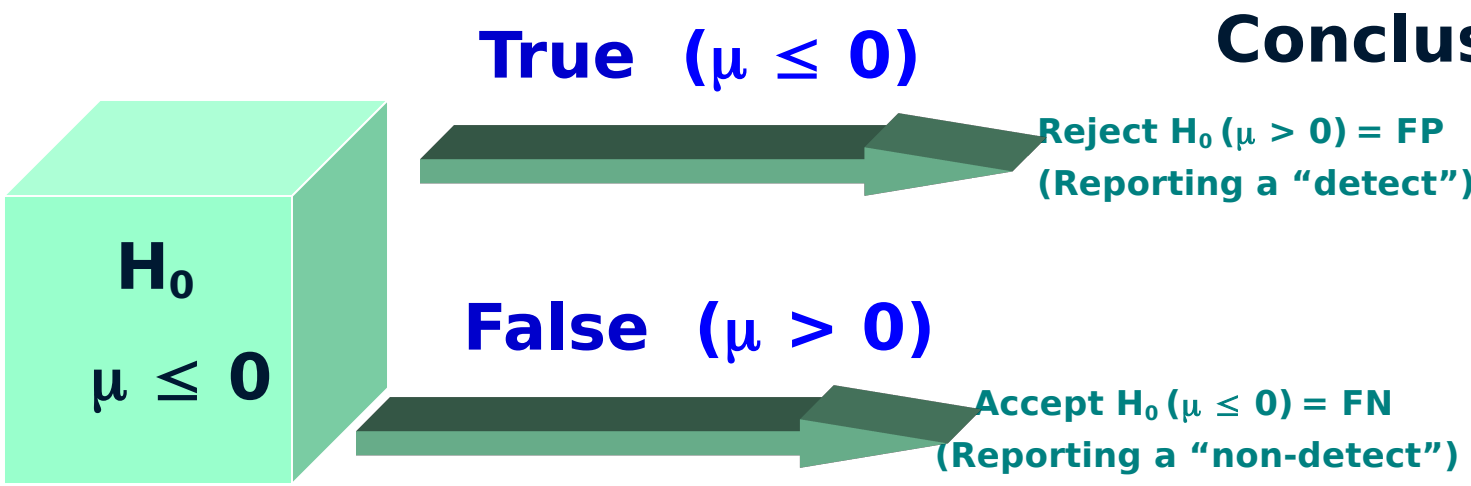
- A “weight of evidence” is provided to reject H_0 (prove H_1) but the failure to reject H_0 does not “prove” H_0; this is an inconclusive result.
  - This is why statisticians say “there was a failure to reject H_0” and not “H_0 was accepted”
  - Exception: The **power** of the hypothesis test (ability to detect differences between H_0 and H_1) is adequate.
- Hypothesis tests need to satisfy tolerances for decision errors.

Decision Errors

Decision	H_0 True (T)	H_0 False (F) (H_1 True)
Do not reject H_0 ("accept" H_0) →	(Correct Decision) $(1 - \alpha)100\%$ Confidence Level (CL)	Type II Error, β False Negative (FN) ←
Reject H_0 → (accept H_1) (e.g., p-value < α)	Type I Error, α False Positive (FP) Significance Level	← (Correct Decision) $(1- \beta)100\%$ Power of Test

Decision Errors for Chemists

- H_0 = True but reject H_0 = Type I error
  - FP – Reporting a difference that does not exist.
- H_0 = False but "accept" H_0 = Type II error (FN)
  - FN – Failing to report a difference that does exist.



Types of Hypothesis Tests

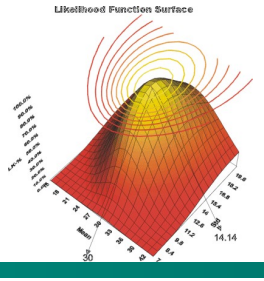
- **One-sample versus multi-sample:** Null hypothesis involves one vs. > one populations.
- **One-tailed (or one-sided) versus two-tailed**: Null hypothesis is an inequality vs. equality.

$H_0: \mu \leq 10, \ H_1: \mu > 10$ **1-sample, 1-taile**

$H_0: \mu = 10, \ H_1: \mu \neq 10$ **1-sample, 2-taile**

$H_0: \mu_{Site} \leq \mu_{BKG}, H_1: \mu_{Site} > \mu_{BKG}$ **2-sample, 1-tailed**

(Continued)



- **Parametric:** Assumes some distribution, typically, a normal distribution.
- **Non-parametric**: Does not assume a particular distribution but other assumptions could be made (e.g., distribution is symmetric).
  - **Note: Applicable to more data sets than parametric tests (e.g., normality not needed) but requires larger sample size for same level of confidence.**

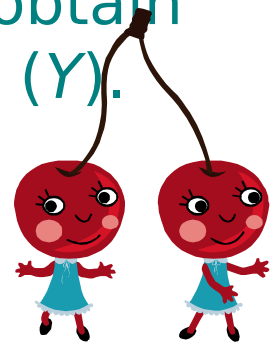
(Continued)

- **Independent variables**: Sample (measurements) from 1st population taken independently of sample from 2nd population.

  Collect sample from study area (*X*) and background (*Y*) to compare means μ_{Site} and μ_{BKG}.

- **Paired variables**: Variables not independent:

  Homogenized and split an aliquot of soil to obtain field test results (*X*) and fixed-lab results (*Y*).



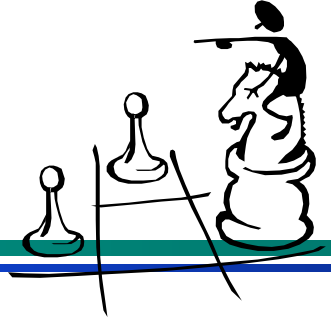
Common Hypothesis Tests

Type of Test	**Parametric** (Compare means)	**Nonparametric** (Compare distributions or medians)
One-sample Also used for paired variables, (X, Y)	t-test	Wilcoxon signed rank Sign test
Two-sample	t-test with equal or unequal variances	Mann-Whitney/Wilcoxon
Multi-sample	ANOVA	Kruskal-Wallis

When should H_0 be rejected?

- Reject H_0 when it is unlikely that H_0 is true.
- Several equivalent approaches:
  - P-values
  - Confidence intervals
  - Critical values

P-Value Approach



- Simplest and preferred method to reject H_0. Calculated by statistical software.
- **P-value, *p***: Probability H_0 is true (given the observed experimental data or measurements).
- H_0 is rejected when *p* (the likelihood H_0 is true) is small (e.g., $p < 0.01$ - 0.1).
- α = Tolerance for Type I error. **Reject H_0 if $p < \alpha$**.

(Continued)

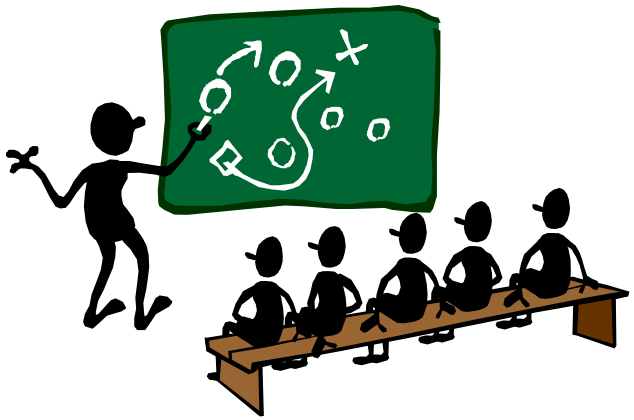
- Terminology: *Reject H_0 at (1 - p)100% confidence or p100% significance.*

  Example: $p = 0.3 \rightarrow$ Reject H_0 at 70% confidence or 30% significance (decision will be correct 70% of time).

- Typically, p-value for two-tailed hypothesis test = 2 $\times$ p-value for one-tailed test.

Confidence Interval (CI) Approach

- Commonly used for one-sample one-tailed hypothesis tests.
- Reject H_0 by comparing UCL or LCL of population parameter to a numerical threshold.



Example of CI Approach

Case I: $H_0: \mu \geq 10$, $H_1: \mu < 10$

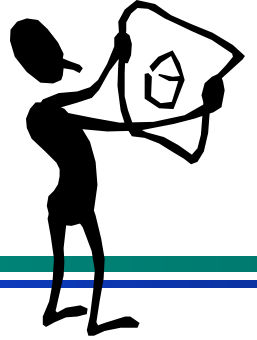
Case II: $H_0: \mu < 10$, $H_1: \mu \geq 10$

DQO Process: $\alpha = 0.05$ (95% confidence level)

Case I: Reject H_0 if 95% UCL< 10.

Case II: Reject H_0 if 95% LCL > 10.

Critical Value Approach



- Calculate test statistic λ (using sample data) and compare λ to "critical value," λ_α.
- Reject H_0 if $\lambda < \lambda_\alpha$ or $\lambda_\alpha > \lambda$. This means $p < \alpha$
- Method to calculate λ and comparison ($\lambda < \lambda_\alpha$ vs. $\lambda_\alpha > \lambda$) depends on nature of test.
- Tables list values of λ_α (e.g., $\alpha = 0.05$ and 0.01). λ_α is usually a percentile of a distribution (e.g., $\lambda_{\alpha = 0.05} = Z_{1-\alpha = 0.95}$).

(Continued)

- Statistic λ may be compared with critical value λ_α for several values of α.

Example:

H_0 is rejected because $\lambda_{\alpha = 0.2} < \lambda$ ($p < 0.2$) but $\lambda_{\alpha = 0.05} > \lambda$.

$\lambda_{\alpha = 0.2} < \lambda < \lambda_{\alpha = 0.05}$ means $0.05 < p < 0.2$.

Example of Critical Value Approach

(Assumes normality)

$H_0: \mu \geq 10$, $H_1: \mu < 10$.

- CI Approach: Reject H_0 if 95% UCL < 10:

  $95\%\ UCL = \bar{x} + t_{n-1,\ 0.95}\ s/\sqrt{n} < 10$

- Critical Value Approach: Reject H_0 if

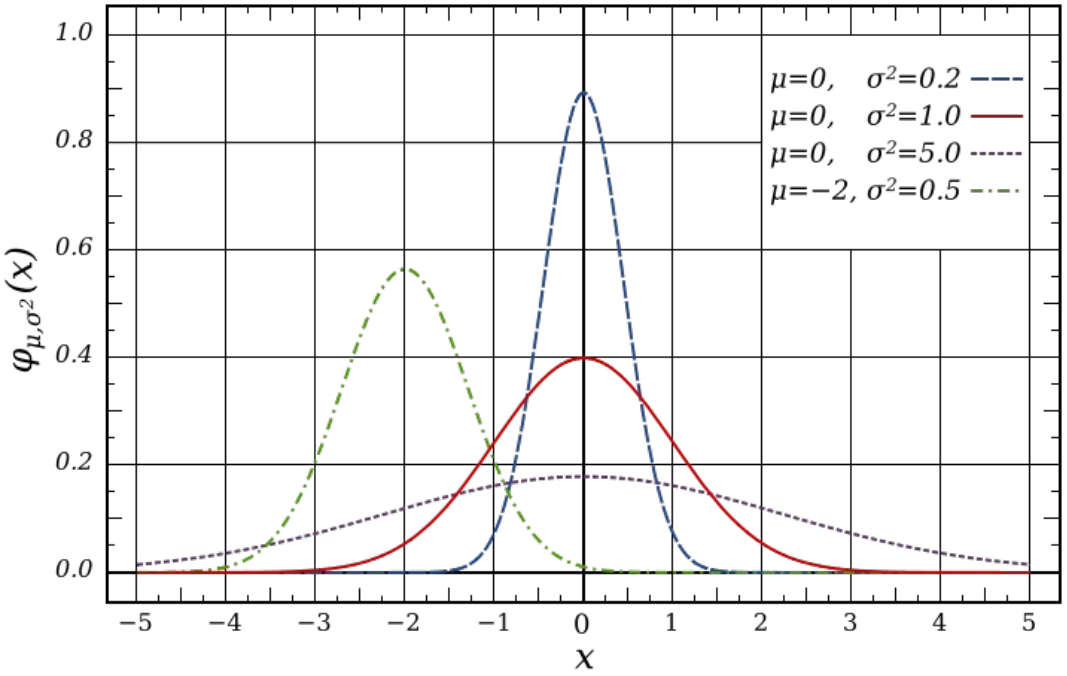
  $$t_{n-1,\ 0.95} < \frac{(10 - \bar{x})}{(s/\sqrt{n})} = t$$

Re-write inequality

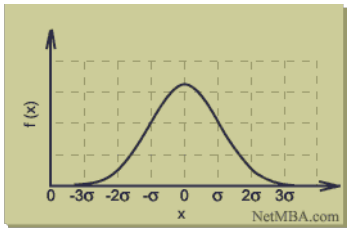
critical value, $\lambda_{\alpha = 0.05}$

test statistic, λ

Part 1.6
Tests for Normality



Evaluating Normality

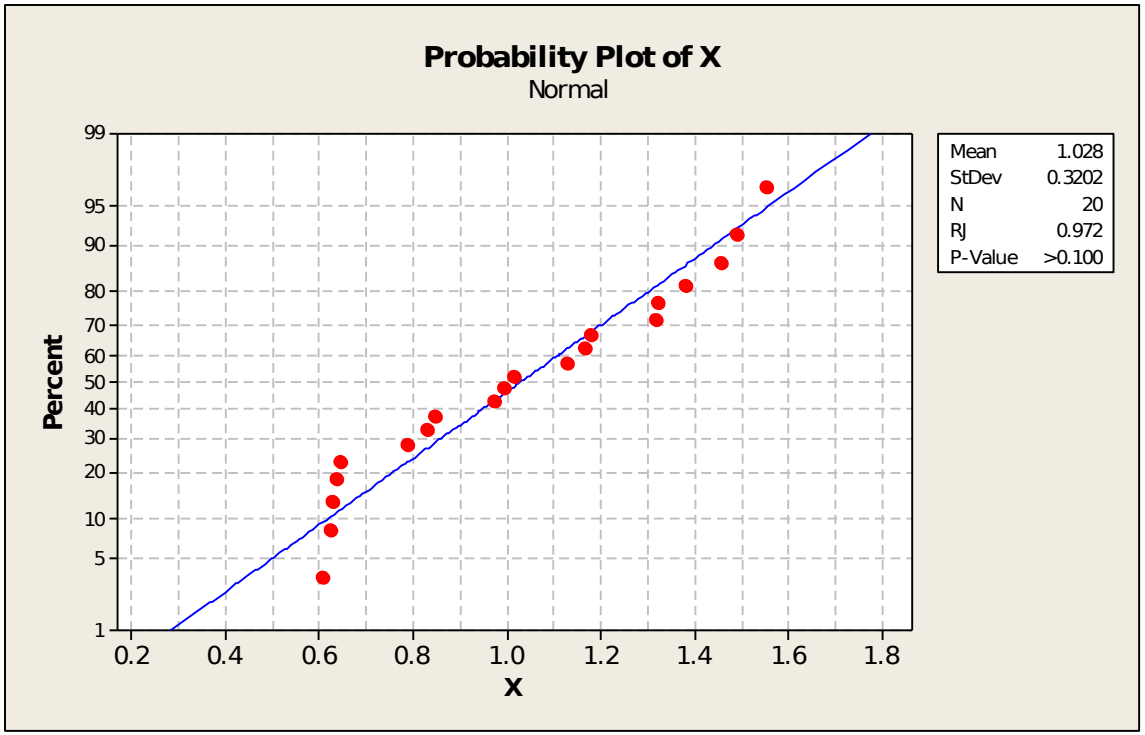


- Evaluate normality using statistical hypothesis tests and plots.
- H_0: X is normal, H_1: X is not normal
- Statistical software packages usually output p-values for normality tests. Reject H_0 if p-value $< \alpha$.
  - Example: $p < \alpha = 0.05$. Conclude distribution is not normal with at least $(1-\alpha)100\% = 95\%$ confidence.

Hypothesis Test & Normality Probability Plot

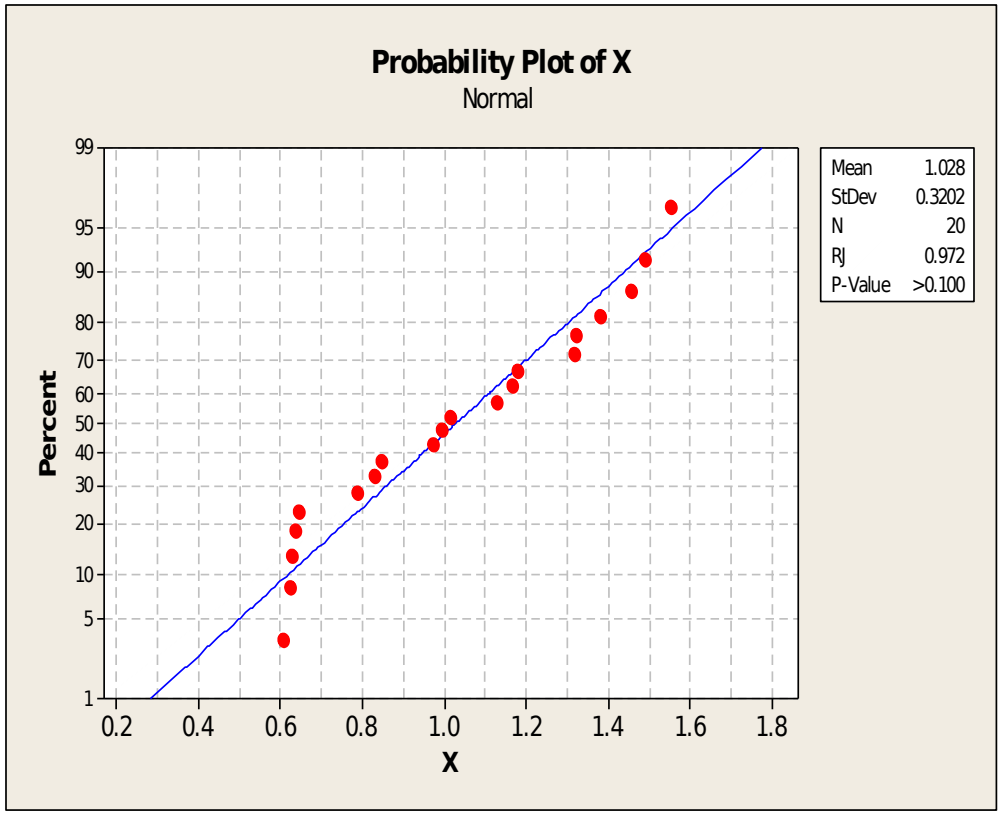
Cannot reject H_0 at 95% CL as $p > 0.1$

Points fall on straight line suggesting normality



Ryan-Joiner normality test (using MiniTab)

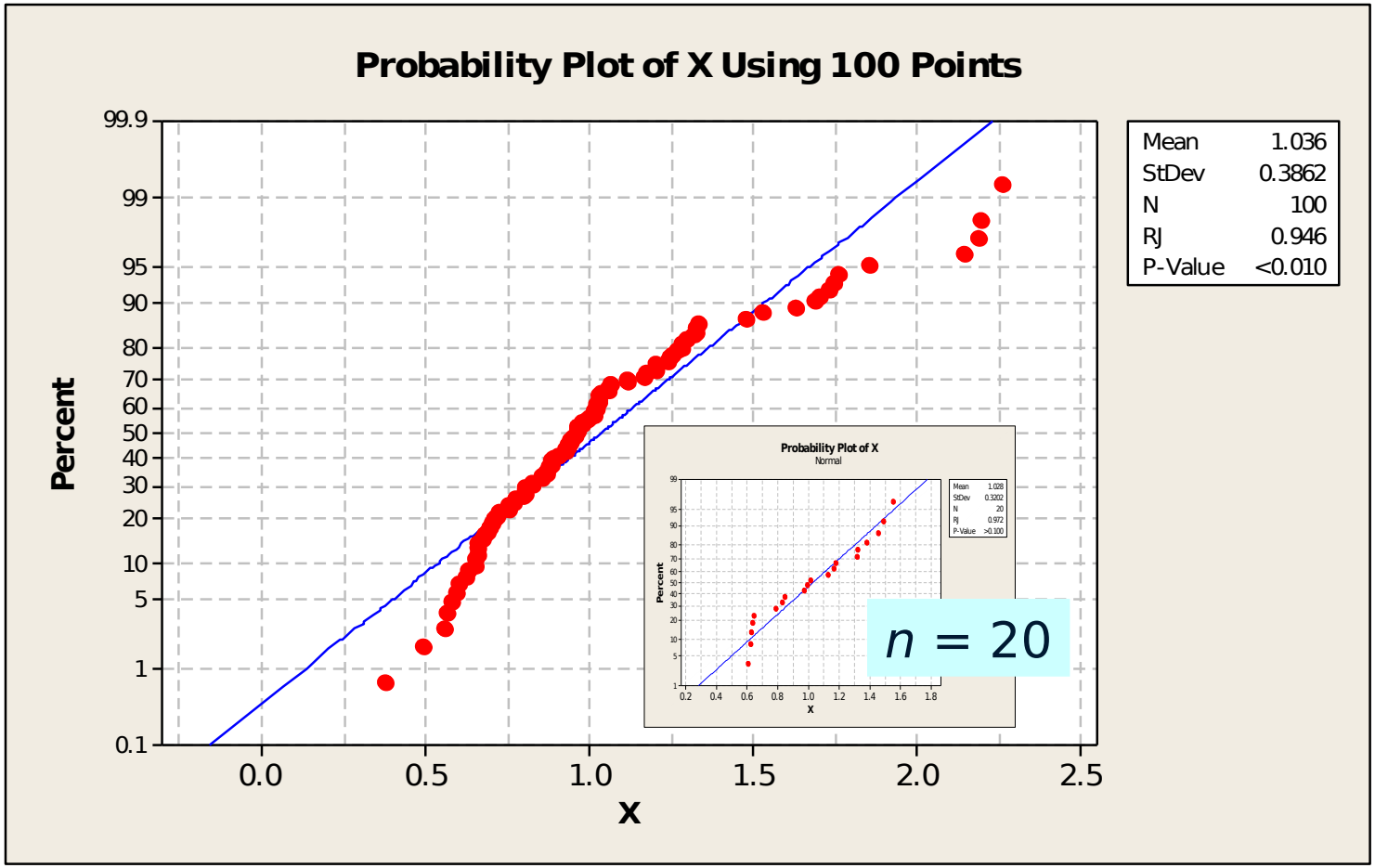
Does $p > 0.1$ mean the distribution is normal?



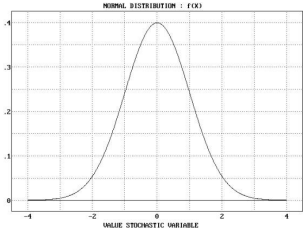
The failure to reject assumption of normality (H_0) is an inconclusive result. Distribution is actually lognormal. Sample size ($n = 20$) was too small to detect deviation from normality.

Same distribution with 100 (rather than 20) points

$p < 0.01$; distribution is not normal.



Testing for Normality Using Critical Value Approach



- Shapario-Wilk test
  - Calculate Sapario-Wilk statistic W (test statistic λ) .
  - If $W < W_\alpha$ (critical value, λ_α) distribution not normal with (1-α)100% confidence (e.g., α = 0.01 or 0.05).
  - If $W \geq W_\alpha$, distribution MAY be normal (inconclusive result).
  - Test available in Visual Sampling Plan (VSP).

Simple Non-rigorous Test for Normality

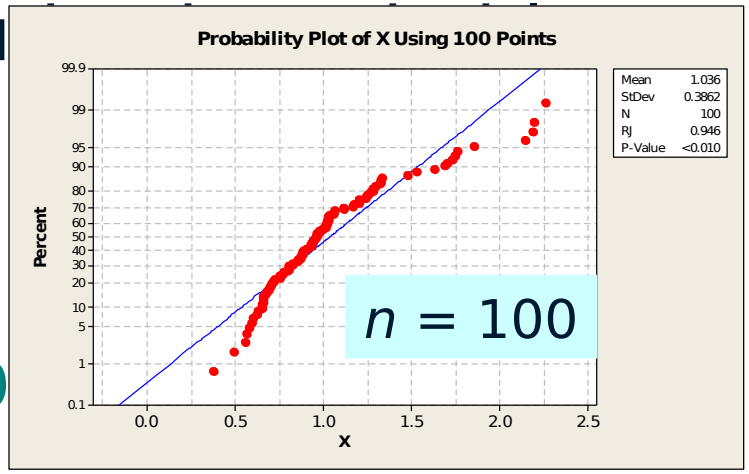
- If $X > 0$ (e.g., concentrations will be positive), calculate percent relative standard deviation:

$$\%RSD = 100\,(s/\bar{x})$$

- If %RSD > 30%, distribu
normal.

Example:

%RSD = (0.39/1.0)100 = 39



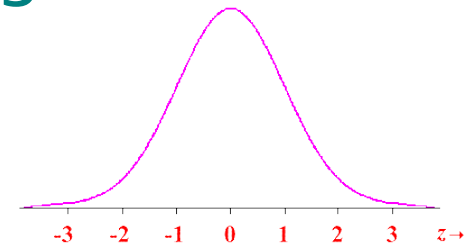
Why does normality depend on the %RSD ?

- Why would it be unlikely for a distribution of positive values to be normal if %RSD > 30%?

99% of values fall within $\bar{x} \pm 3\,s$ for a normal distribution.

$s / \bar{x} > 1/3 \rightarrow \bar{x} - 3s = \bar{x} - 3(\bar{x}/3) < 0$

Large standard deviation gives negative conc.



Part 1.7
Evaluating Background Concentrations

Background (BKG) Comparisons

- Use hypothesis tests to evaluate compare study area and background concentrations. ✓

H_0: $\mu_{Site} \leq \mu_{BKG}$, H_1: $\mu_{Site} > \mu_{BKG}$

Q1: Why not H_0: $\mu_{Site} \geq \mu_{BKG}$, H_1: $\mu_{Site} < \mu_{BKG}$?

A1: Would need to show site mean << BG mean !

Q2: Why may a regulator object to this Hypothesis test?

A2: Site is "dirty" if H_0 is rejected, but site is not necessary "clean" if H_0 is not rejected!

Selecting H_0 for BKG Comparisons

- **Form 1**: H_0: $\mu_{Site} \leq \mu_{BKG}$, H_1: $\mu_{Site} > \mu_{BG}$
- **Form 2**: H_0: $\mu_{Site} \geq \mu_{BKG} + S$, H_1: $\mu_{Site} < \mu_{BG} + S$
  - Site "clean" if H_0 rejected. But what is S ?
  - S = what is considered to be a "significant difference" between Site and BKG, $\mu_{Site} - \mu_{BKG}$, determined by **consensus** during project planning.
  - S is added to each BKG value ($x_i \rightarrow x_i + S$) and the statistical test is subsequently done.

Determining S

- **Form 2**: H_0: $\mu_{Site} \geq \mu_{BKG} + S$, H_1: $\mu_{Site} < \mu_{BG} + S$
  - Q1: Why would it be undesirable for S to be very small?
    A1: If S ≈ 0 and site is clean, we would need to show site mean << BG mean ! Increases cost from FPs.
  - Q2: Why would it be undesirable for S to be very large?
    A2: We may conclude site is "clean" when $\mu_{Site} >> \mu_{BKG}$. Not conservative for risk assessment because of FNs.

Determining S

H_0: $\mu_{Site} \geq \mu_{BKG} + S$, H_1: $\mu_{Site} < \mu_{BG} + S$

- Often, S = 1 – 3 *s* of BKG data.
- Start with some small value of $S = S_0$. If H_0 is not rejected, add larger and larger values of S to BGK data until H_0 is rejected. Then decide if this value, S = S´, is too large. If S is too large, conclude site is “dirty” (e.g., S = 2 × BKG mean)

Types of Hypothesis Tests for BKG Comparisons

- If BKG data and Site data sets are both (i) normal and (ii) consist of all detects, do two-sample t-test to compare means.
- Otherwise, do non-parametric two-sample tests.
  - Wilcoxon-Mann-Whitney test if there is one RL.
  - Gehan test or generalized Wilcoxon test if there are multiple RLs for non-detects.

Form 1: Nonparametric Tests ✓

- H_0: $P(y_i > x_i) = 0.5$

  BKG values (x_i) & Site values (y_i) from same distribution

  H_1: $P(y_i > x_i) > 0.5$

  Site values (y_i) tend to be larger than BKG values (x_i)

- No assumptions made about distributions.
  If distributions have same shapes, then tests compare medians.

$$H_0 : \tilde{\mu}_{Site} \leq \tilde{\mu}_{BKG} \qquad H_1 : \tilde{\mu}_{Site} > \tilde{\mu}_{BKG}$$

How to do BKG comparisons if *n* is small

- If study area sample size is too small to do hypothesis test (e.g., $n = 1$ or 2) , calculate BKG UPL for next *n* future observations and **compare Site maximum to BKG UPL**. Site is "dirty" if maximum > 99% UPL.

- Use a non-parametric UPL if BKG data set is not normal (e.g., or lognormal) or contains non-detects. (ProUCL software calculates several types of UPLs.)

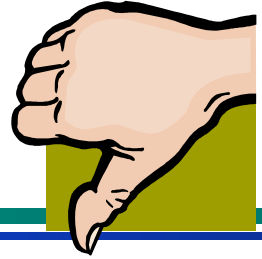
How to NOT do BKG Comparisons

- Do not compare Site maximum to **BKG UTL** or **BKG maximum**, especially if Site sample size *n* is large !

FPs (concluding Site is "dirty" when it is "clean") will likely result. As many as 5% of Site data pts may exceed BKG 95% UTL when site is "clean." (Conclude Site is "dirty" if > 5% exceeds BKG UTL.)

$P(FP) \leq 1 - (0.95)^n$. If $n = 10$, $P(FP) \leq 40$

Other things not to do



- Do not discard BKG points on basis of statistical outlier tests without physical justification.
  - If study area statistical outliers are not discarded, neither should BKG outliers (or FPs may occur).
- Do not target only “pristine” areas for BKG.
  - BKG area should represent both native and anthropogenic sources of contamination.
- Do not automatically limit BGK to metals only.
  - PAHs and pesticides have many BKG sources.

Part 2.0
Hypotheses Tests, Decision Errors and VSP

Visual Sampling Plan (VSP)

- Free software (sponsored by EPA and written by Statistical Sciences group at Battelle Pacific Northwest National Lab) that supports DQO development and statistical sampling designs.

- Download current version of software (5.0) and user's guide (13 MB pdf file) from:

http://dqo.pnl.gov/VSP/vspdesc.htm

Some VSP Statistical Capabilities

- User can enter data and do some statistical tests:
  - One-sample and two-sample one-tailed and two-tailed parametric and non-parametric hypothesis tests.
  - Tests for normality.
  - Statistical plots (e.g., histograms & box plots).
  - UCLs of the mean. (However, ProUCL soft
    recommended.)

"Critical Sample Size," n_C

- VSP estimates sample size, n_C, required to achieve tolerances for Type I and Type II errors for specified "important differences" (Δ) to detect. Inputs (blue text) needed to calculate n_C :
  - **Type I error,** α – Probability of rejecting a true H_0.
  - **Type II error,** β – Probability of not rejecting a false H_0.
  - **Power, 1 -** β – Probability of rejecting a false H_0 (i.e., probability of finding a difference when one exists).
  - **s** – standard deviation (expected or calculated from prior sample results)

(Continued)

- Δ = **Effect Size or "Width of Gray Region"** – Smallest difference that is "important" for a statistical test to "detect" (i.e., rejecting a false H_0). For background comparisons Δ = S.

- **Δ/s** – "Relative difference;" smallest significant difference in terms of number of standard deviations (e.g., Δ/s = 0.5, 1, 2…) .

Number of Samples Needed for Acceptable Decision Errors

- Required sample size n_C increases as α, β and Δ decrease and ***s*** (variability) increases.

  Example: H_0: $\mu \geq 10$, H_1: $\mu < 10$; X is normal; $\Delta = \mu - 10$.

$$n_C \approx \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{(\Delta/s)^2} \approx \frac{10-20}{(\Delta/s)^2}$$

- $n_C \uparrow$ if $(\Delta/s) \downarrow$ or $(Z_{1-\alpha} + Z_{1-\beta}) \uparrow$ (α and $\beta \downarrow$) .

  Note: (Δ/s) affects n_C more than α and β.

Some Values of n_c

Δ/s	Normal	Not Normal
0.5	45	74
1	13	24
2	5	12

One-sample, single-tailed hypothesis tests, $\alpha = \beta = 0.05$

Using n_C

- Values of α, β and Δ determined during project planning and s is estimated to calculate n_C.
  - α & $\beta \leq 0.01$ - 0.1
  - When s is unknown, often $\Delta/s = 1 – 2$.
- If H_0 is not rejected but study area sample size $n \geq n_C$, accept H_0. Equivalent to showing **power** is adequate.

Determining Goals for "Completeness"

- Quality Assurance Project Plan (QAPP):

  Objective for percent completeness, %Complete = 90%.

- Sample size need for adequate power:

  $n' \geq n_C / (\%\text{Complete}/100)$

  Example:

  $n_C = 13$ ($\alpha = \beta = 0.05$, $\Delta/s = 1$), %Complete = 90% $\rightarrow$

  $n' = 13/0.9 = 14.4 \rightarrow 15$.

"Completeness" Goals

- Do not calculate completeness on the basis of total number of analytes and methods.

$$\%Completeness = \frac{Number\ of\ usable\ results}{Total\ number\ of\ results} \times 100$$

- Determine for each analyte in each matrix for each study area.

Example

25 soil and 25 groundwater (GW) grabs - 10 for Site A and 15 for Site B – tested for Pb and Cu.

Total results $\neq 100 = (25 + 25) \times 2$

	A Site		**B Site**	
	Pb	**Cu**	**Pb**	**Cu**
Soil	10	10	15	15
GW	10	10	15	15

8 data sets

90% complete:

$0.9 \times n =$ **9,** Site A $0.9 \times n =$ **14,** Site B

Need to show 9 & 14 > n_C.

Determining n_c using VSP

Sampling Goals →

Compare Average to Fixed Threshold

(One-sample hypothesis tests)

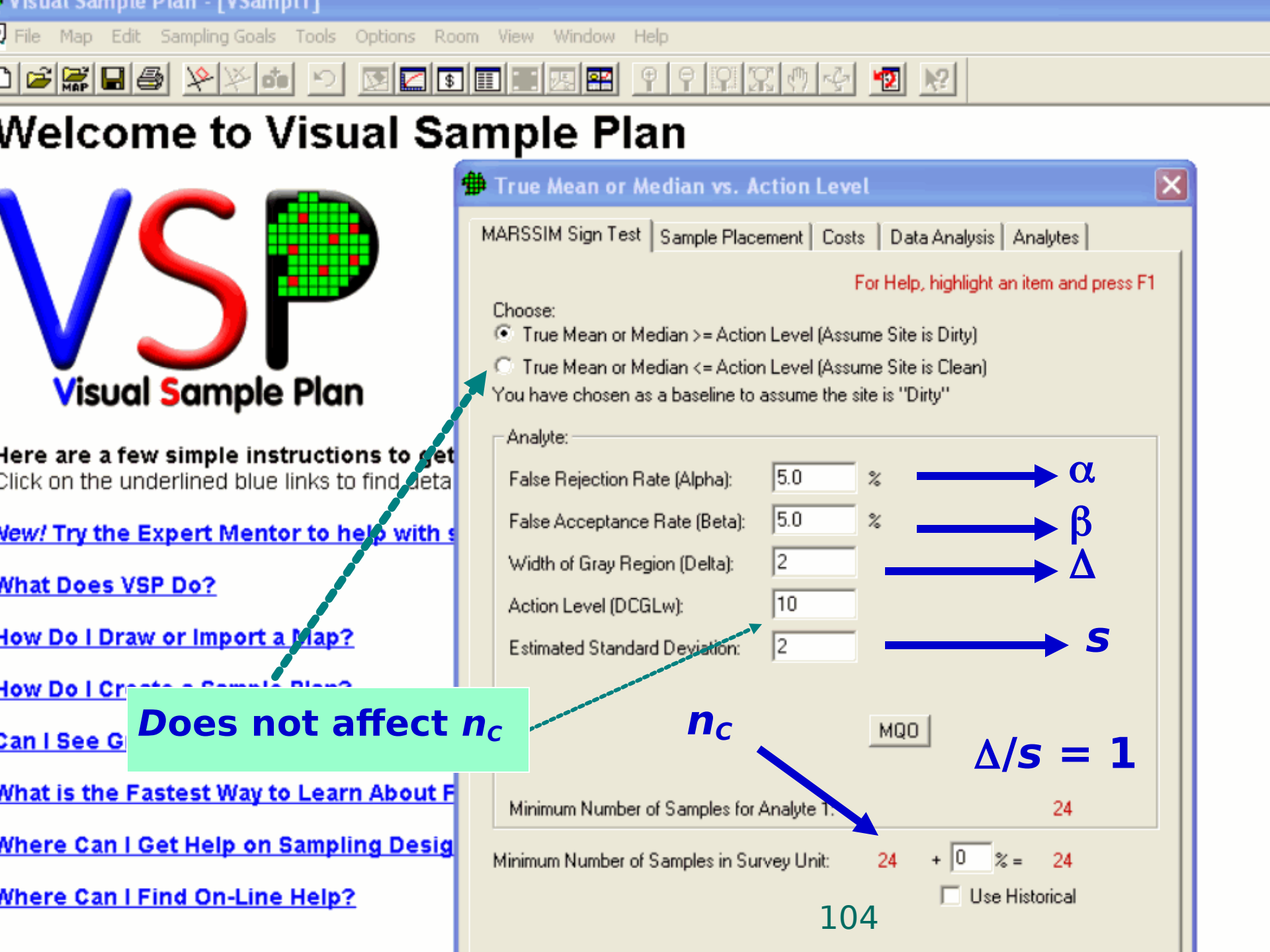
OR

Compare Average to Reference Average

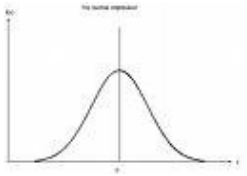
(Two-sample hypothesis tests)

→ **Data not required to be normally distributed**

→ Ordinary Sampling – No distribution assumptions (MARSSIM)


File Map Edit Sampling Goals Tools Options Room View Window Help
Welcome to Visual Sample Plan
Visual Sample Plan
Here are a few simple instructions to get
Click on the underlined blue links to find deta
New! Try the Expert Mentor to help with s
What Does VSP Do?
How Do I Draw or Import a Map?
How Do I Cr
Can I See G
What is the Fastest Way to Learn About F
Where Can I Get Help on Sampling Desig
Where Can I Find On-Line Help?
True Mean or Median vs. Action Level
MARSSIM Sign Test
Sample Placement
Costs
Data Analysis
Analytes
For Help, highlight an item and press F1
Choose:
True Mean or Median >= Action Level (Assume Site is Dirty)
True Mean or Median <= Action Level (Assume Site is Clean)
You have chosen as a baseline to assume the site is "Dirty"
Analyte:
False Rejection Rate (Alpha): 5.0 %
False Acceptance Rate (Beta): 5.0 %
Width of Gray Region (Delta): 2
Action Level (DCGLw): 10
Estimated Standard Deviation: 2
α
β
Δ
s
Does not affect n_c
n_c
MQO
Δ/s = 1
Minimum Number of Samples for Analyte 1: 24
Minimum Number of Samples in Survey Unit: 24 + 0 % = 24
Use Historical

Testing for Normality



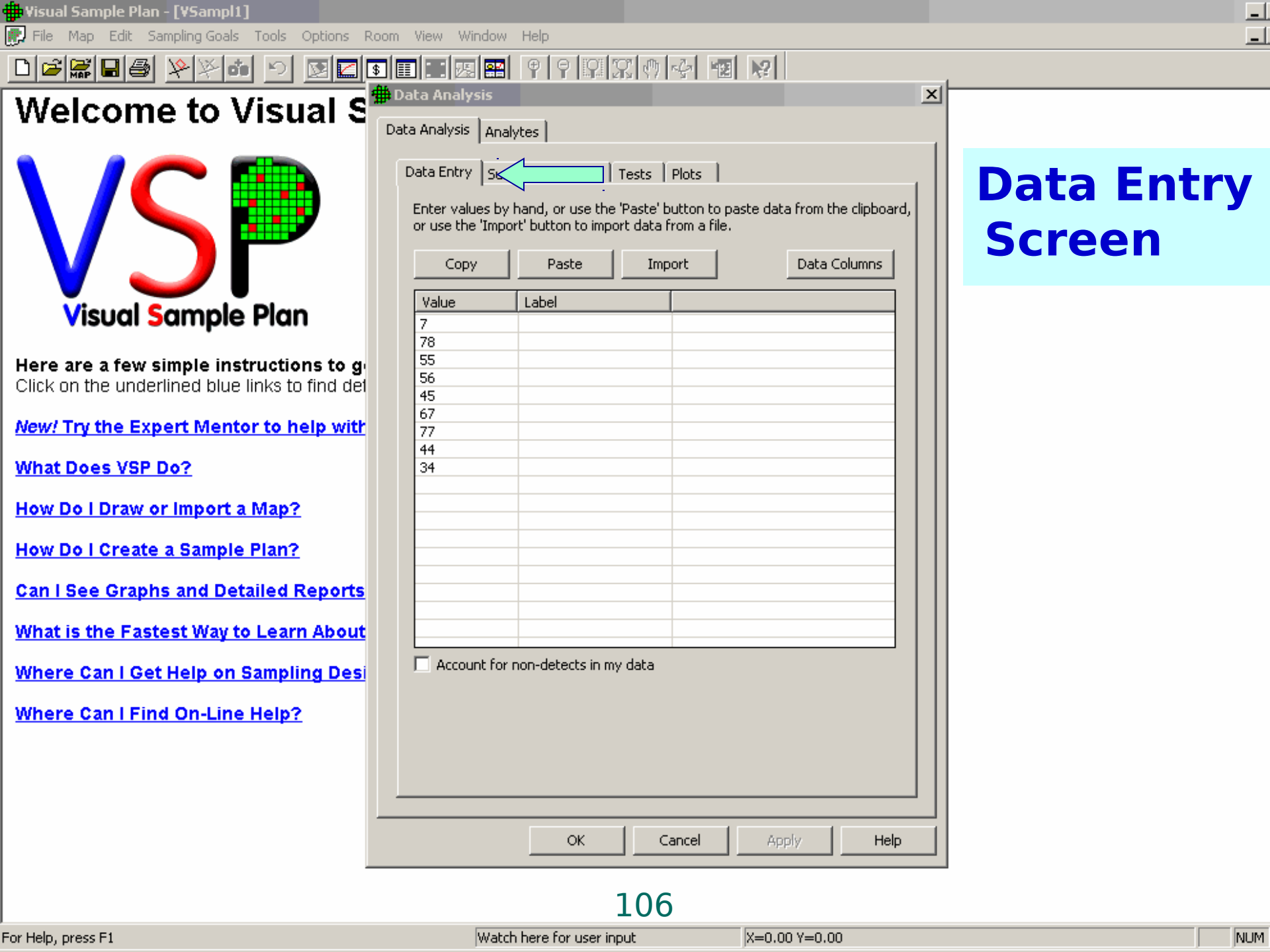
- **Menu**

  Tools → Analyze Data… → Data Entry tab

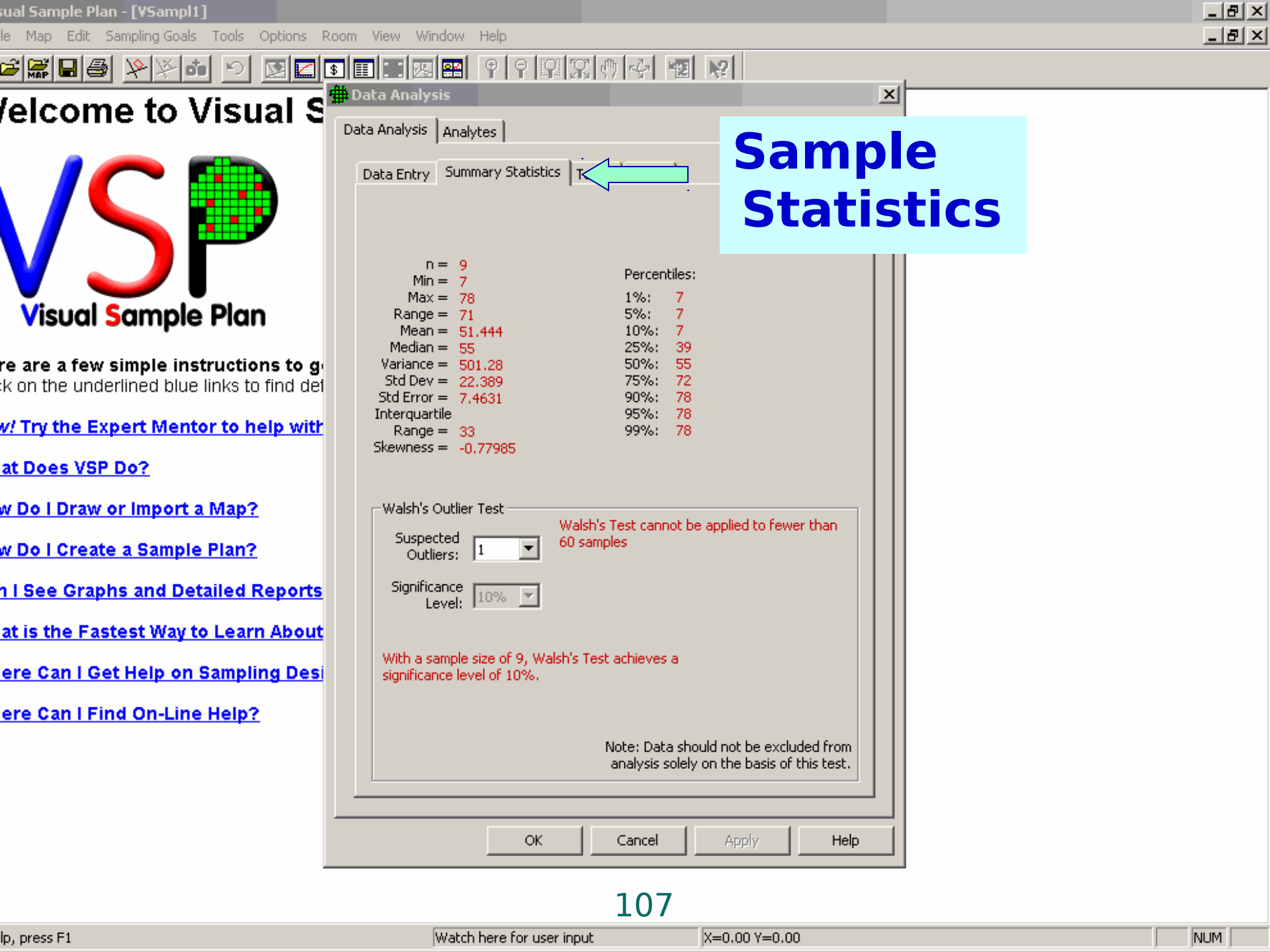
- Enter data manually or use Import button for text file

  Example of .txt file:

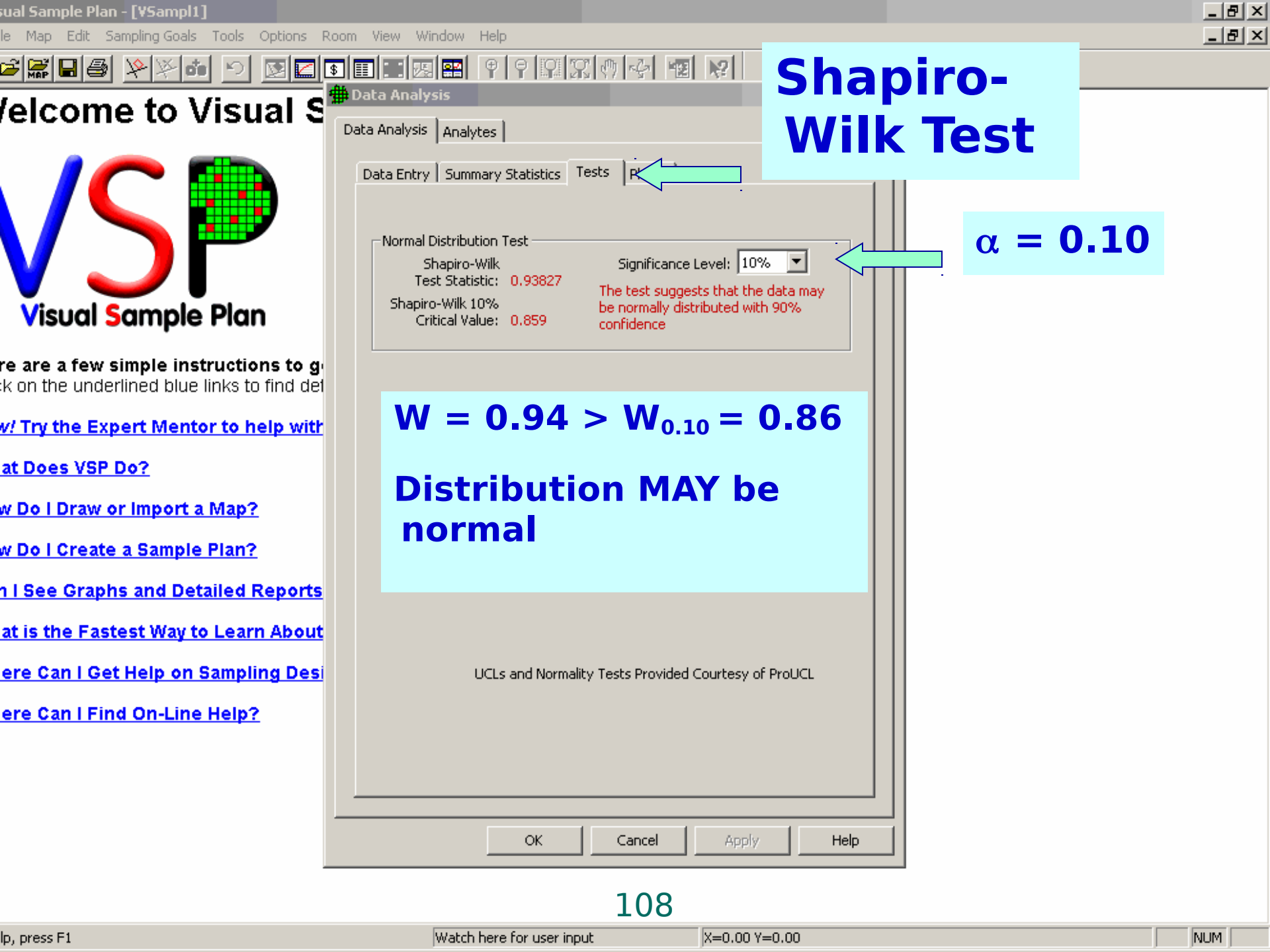
  Value (VSP column heading)
  7 (enter)
  78 (enter)
  …



Data Entry Screen


Sample Statistics
Data Analysis
Data Analysis
Analytes
Data Entry
Summary Statistics
n = 9
Min = 7
Max = 78
Range = 71
Mean = 51.444
Median = 55
Variance = 501.28
Std Dev = 22.389
Std Error = 7.4631
Interquartile Range = 33
Skewness = -0.77985
Percentiles:
1%: 7
5%: 7
10%: 7
25%: 39
50%: 55
75%: 72
90%: 78
95%: 78
99%: 78
Walsh's Outlier Test
Suspected Outliers: 1
Significance Level: 10%
Walsh's Test cannot be applied to fewer than 60 samples
With a sample size of 9, Walsh's Test achieves a significance level of 10%.
Note: Data should not be excluded from analysis solely on the basis of this test.
OK
Cancel
Apply
Help
Visual Sample Plan
Map Edit Sampling Goals Tools Options Room View Window Help

Shapiro-Wilk Test



$\alpha = 0.10$

$W = 0.94 > W_{0.10} = 0.86$

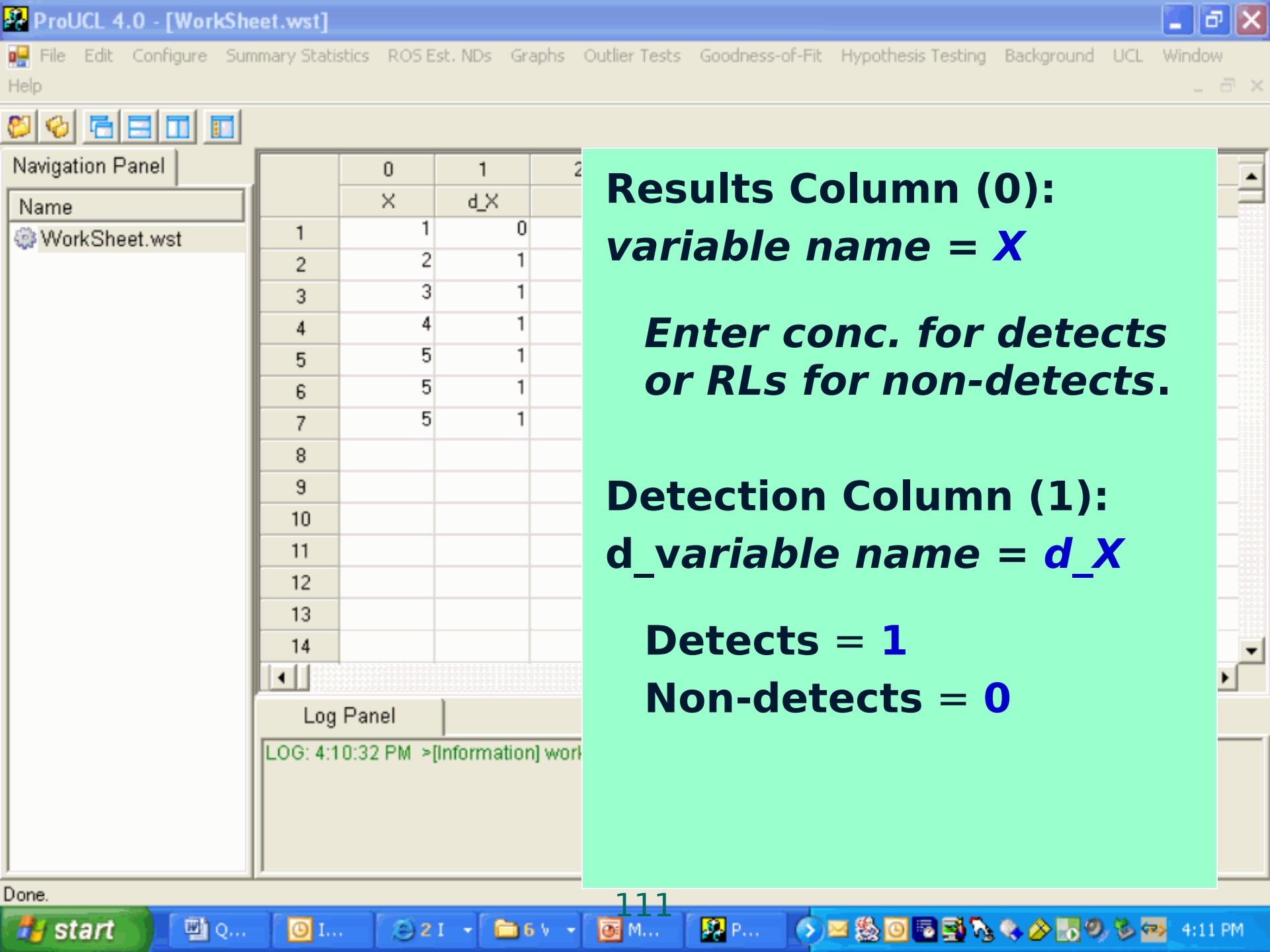
Distribution MAY be normal

UCLs and Normality Tests Provided Courtesy of ProUCL

Part 3.0
ProUCL Statistical Software

ProUCL Version 4.00.02

- Free EPA statistical software with User's Guide.
- $n \geq 5$ with at least 2 detects to calculate UCLs.
- $n \geq 10$ – 15 recommended.
- Also does
  - Descriptive statistics (e.g., minimum and medium)
  - One and two-sample hypothesis tests
  - Tests for normality
  - Outlier tests
  - UTLs and UPLs calculations



Results Column (0):

variable name = X

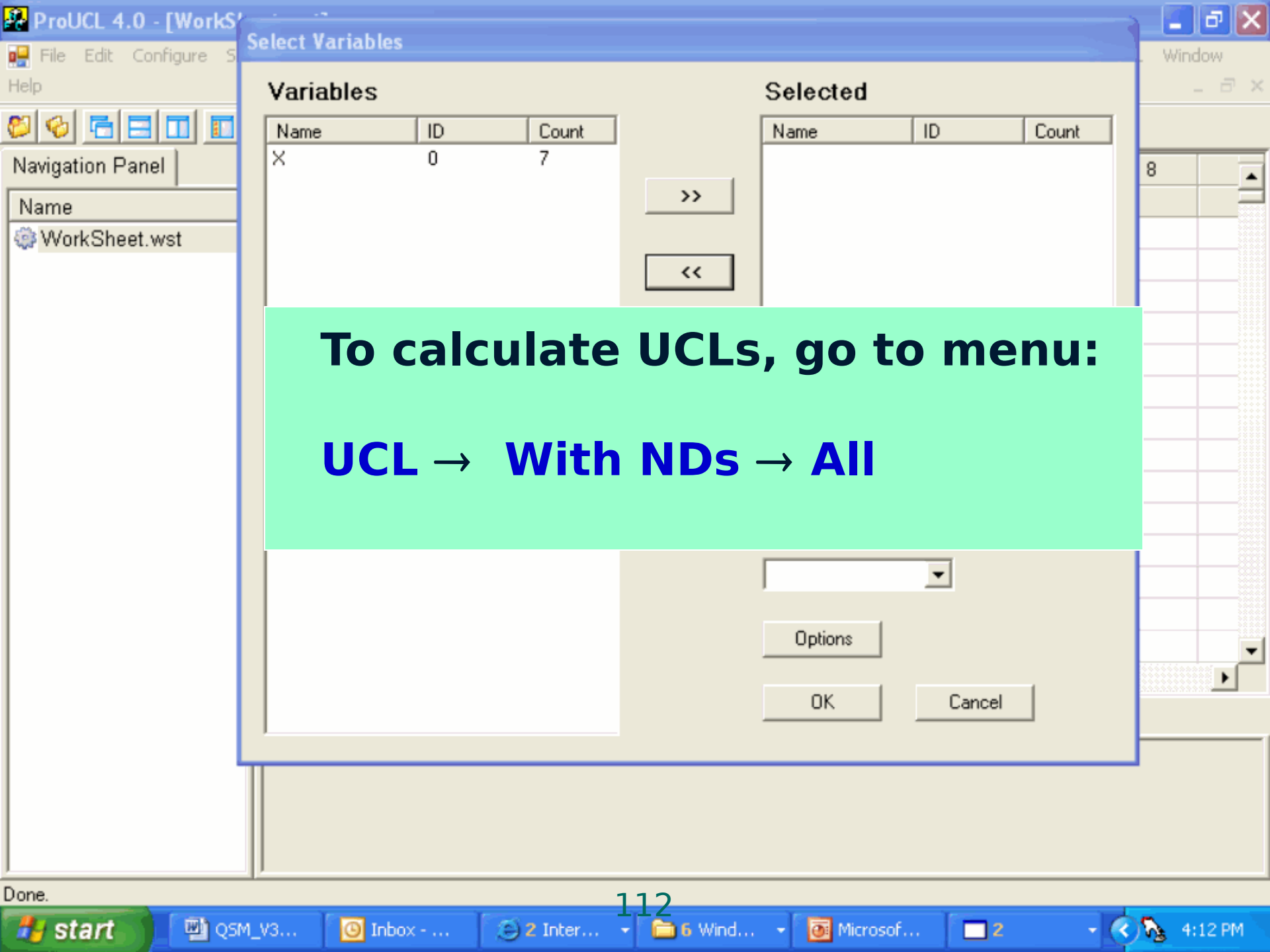
Enter conc. for detects or RLs for non-detects.

Detection Column (1):

d_*variable name* = *d_X*

Detects = 1

Non-detects = 0


ProUCL 4.0 - [WorkS
File Edit Configure S
Help
Window
Navigation Panel
Name
WorkSheet.wst
Select Variables
Variables
Name ID Count
X 0 7
>>
<<
Selected
Name ID Count
8
To calculate UCLs, go to menu:
UCL → With NDs → All
Options
OK
Cancel
Done.
start
QSM_V3...
Inbox - ...
2 Inter...
6 Wind...
Microsof...
2
4:12 PM

ProUCL 4.0 - [ALLwND_UCL.ost]

File Edit Configure Window Help

Navigation Panel

Name

WorkSheet.wst

ALLwND_UCL.ost

General Statistics

Number of Valid Data	7	Number of Detected Data	6
Number of Distinct Detected Data	4	Number of Non-Detect Data	1
		Percent Non-Detects	14.29%

Raw Statistics		**Log-transformed Statistics**	
Minimum Detected	2	Minimum Detected	0.693
Maximum Detected	5	Maximum Detected	1.609
Mean of Detected	4	Mean of Detected	1.334
SD of Detected	1.265	SD of Detected	0.373
Minimum Non-Detect	1	Minimum Non-Detect	0
Maximum Non-Detect	1	Maximum Non-Detect	0

Warning: There are only 4 Distinct Detected Values in this data

Log Panel

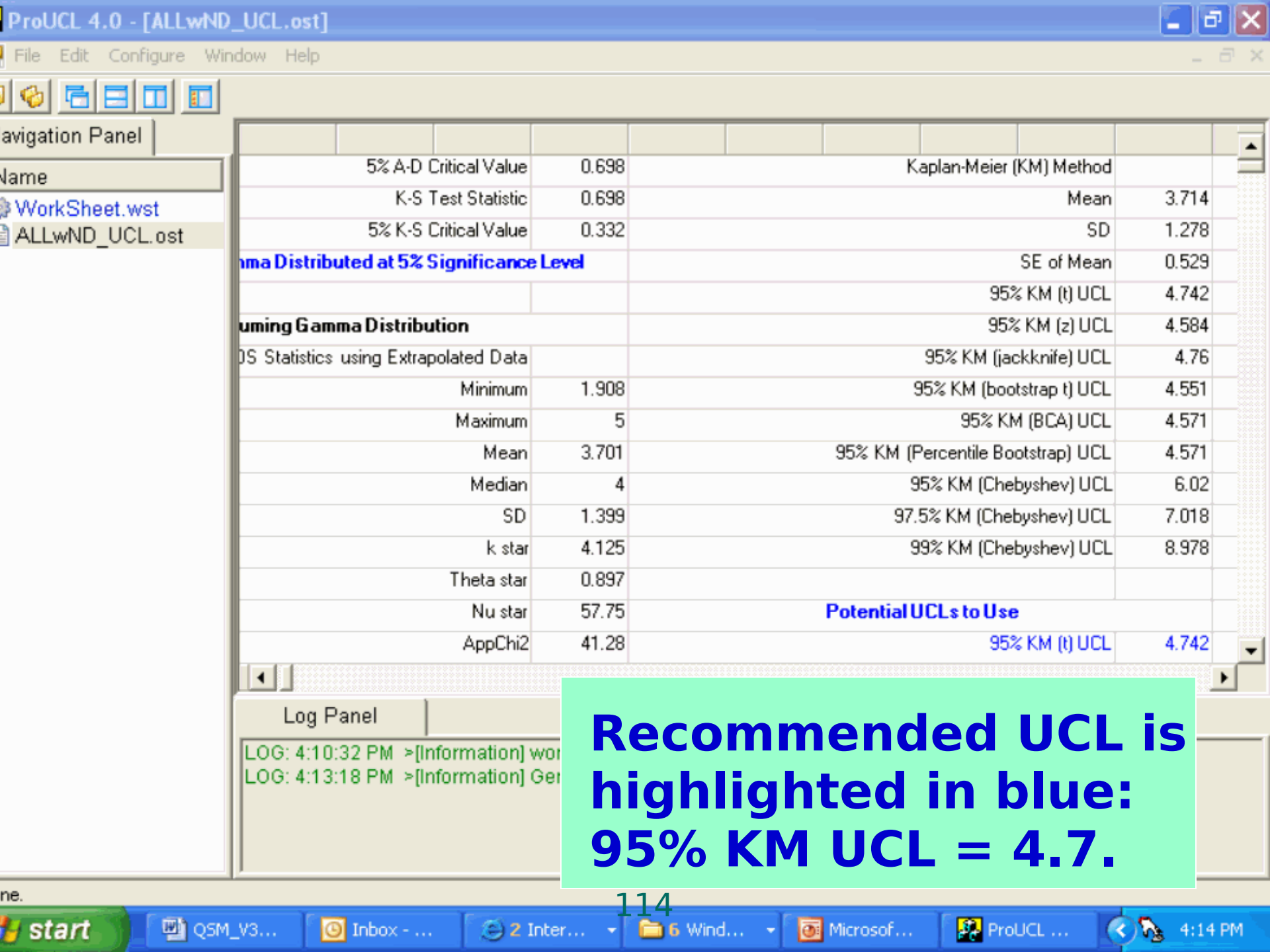
LOG: 4:10:32 PM >[Informatio

LOG: 4:13:18 PM >[Informatio

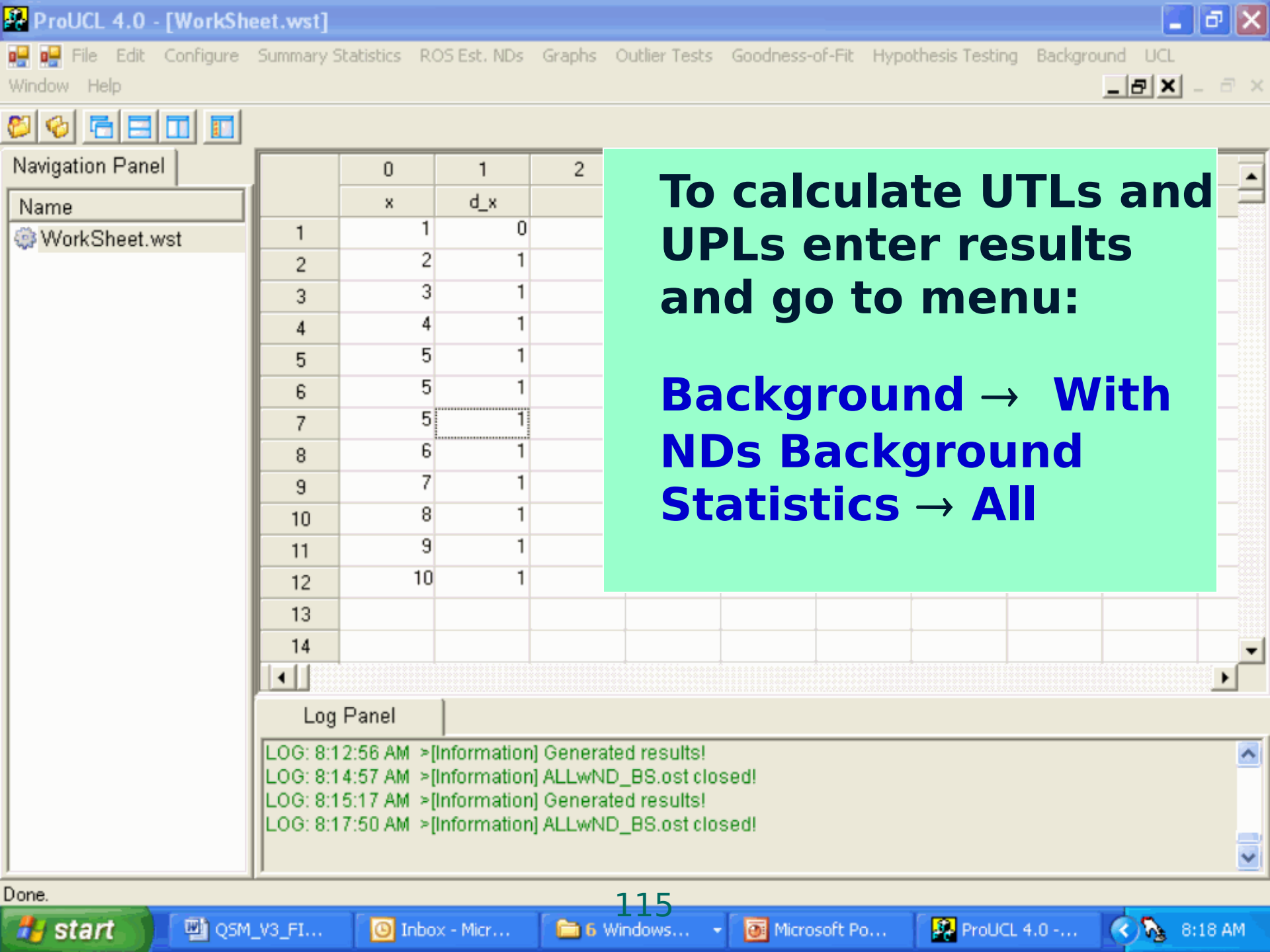
Excel spreadsheet with descriptive statistics and UCLs

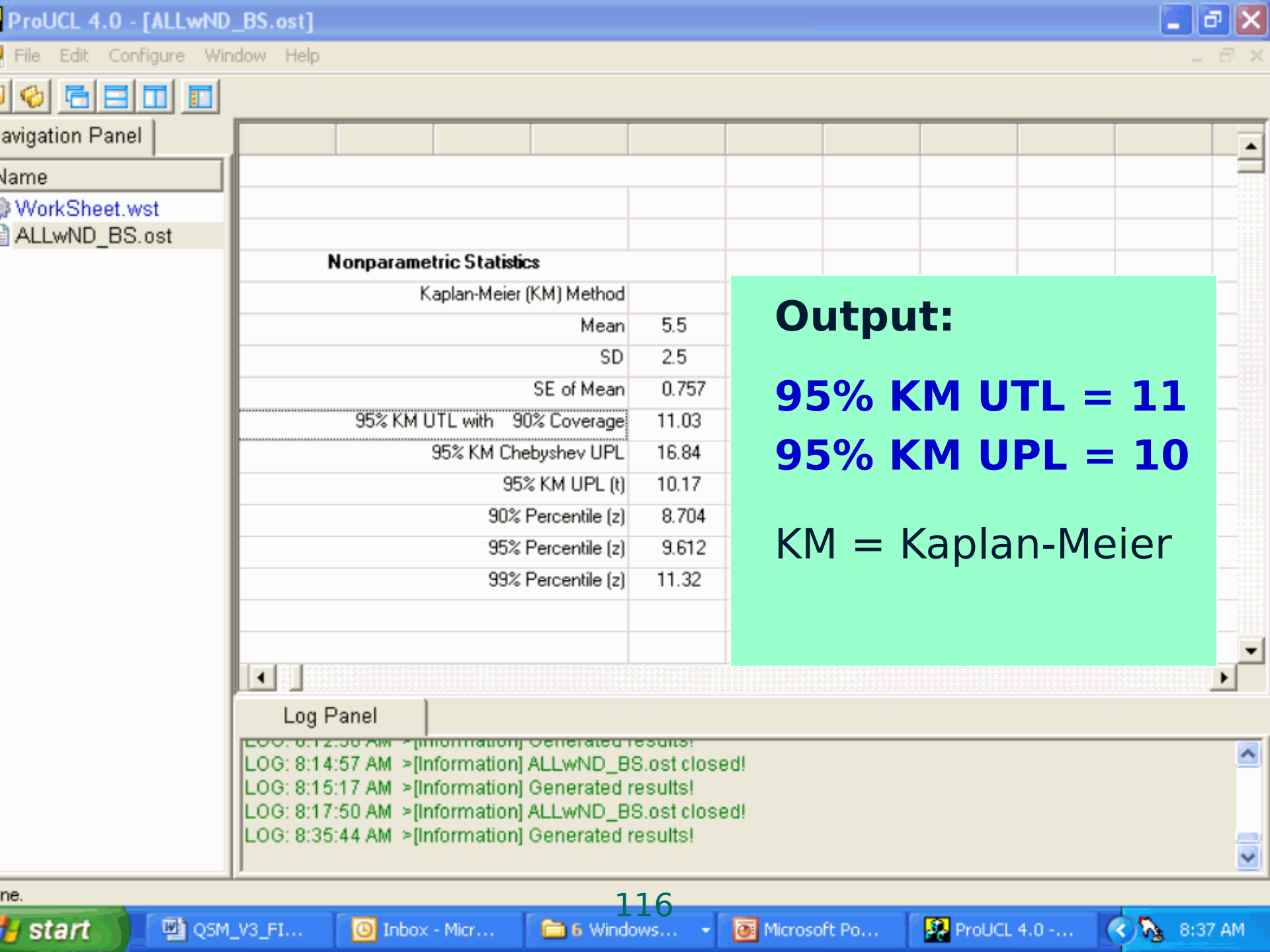
Done.

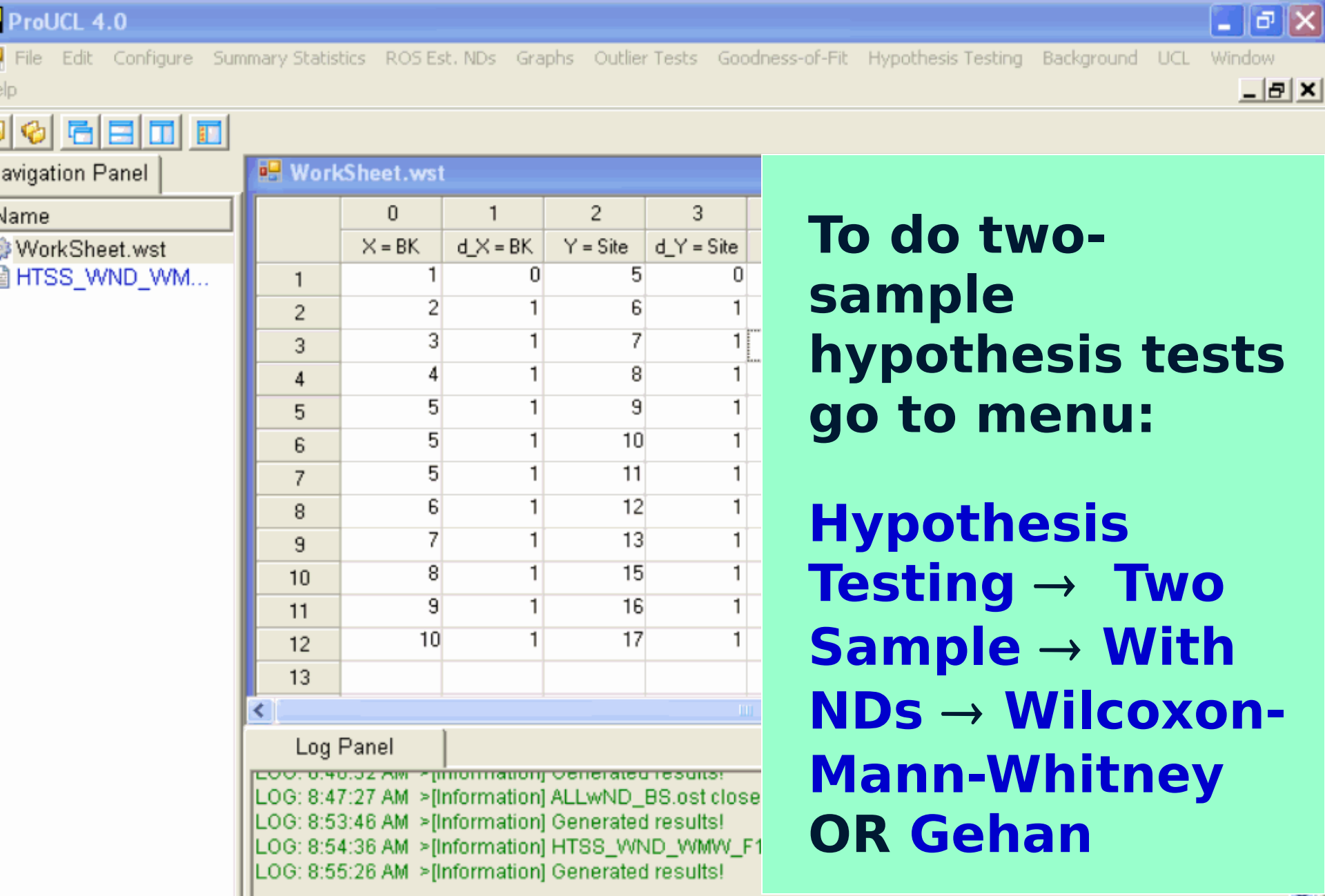
start QSM_V3... Inbox - ... 2 Inter... 6 Wind... Microsof... ProUCL ... 4:13 P



Recommended UCL is highlighted in blue: 95% KM UCL = 4.7.

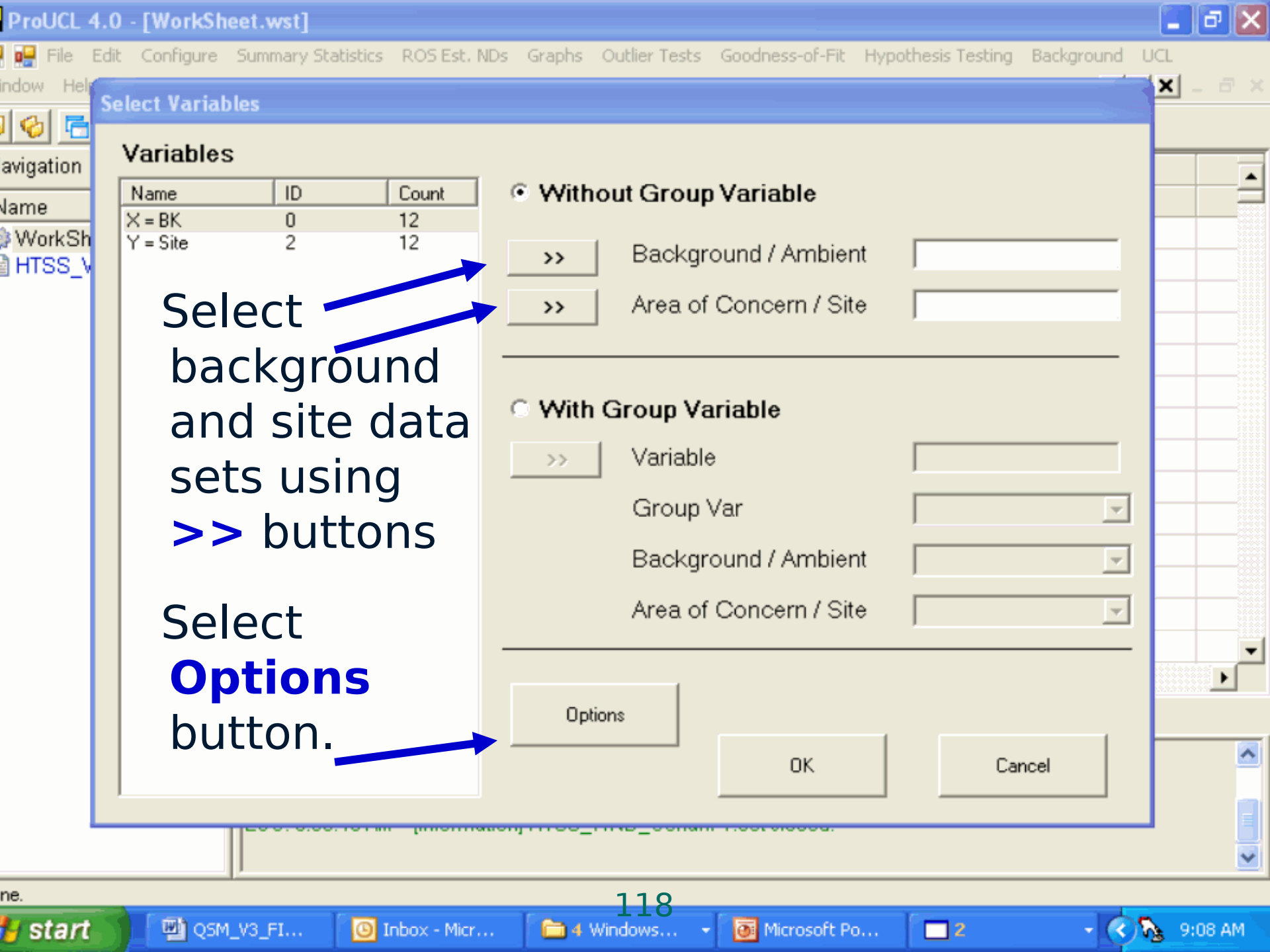

ProUCL 4.0 - [WorkSheet.wst]
File Edit Configure Summary Statistics ROS Est. NDs Graphs Outlier Tests Goodness-of-Fit Hypothesis Testing Background UCL
Window Help
Navigation Panel
Name
WorkSheet.wst
0 1 2
x d_x
1 1 0
2 2 1
3 3 1
4 4 1
5 5 1
6 5 1
7 5 1
8 6 1
9 7 1
10 8 1
11 9 1
12 10 1
13
14
To calculate UTLs and UPLs enter results and go to menu:
Background → With NDs Background
Statistics → All
Log Panel
LOG: 8:12:56 AM >[Information] Generated results!
LOG: 8:14:57 AM >[Information] ALLwND_BS.ost closed!
LOG: 8:15:17 AM >[Information] Generated results!
LOG: 8:17:50 AM >[Information] ALLwND_BS.ost closed!
Done.
start
QSM_V3_FI...
Inbox - Micr...
6 Windows...
Microsoft Po...
ProUCL 4.0 -...
8:18 AM

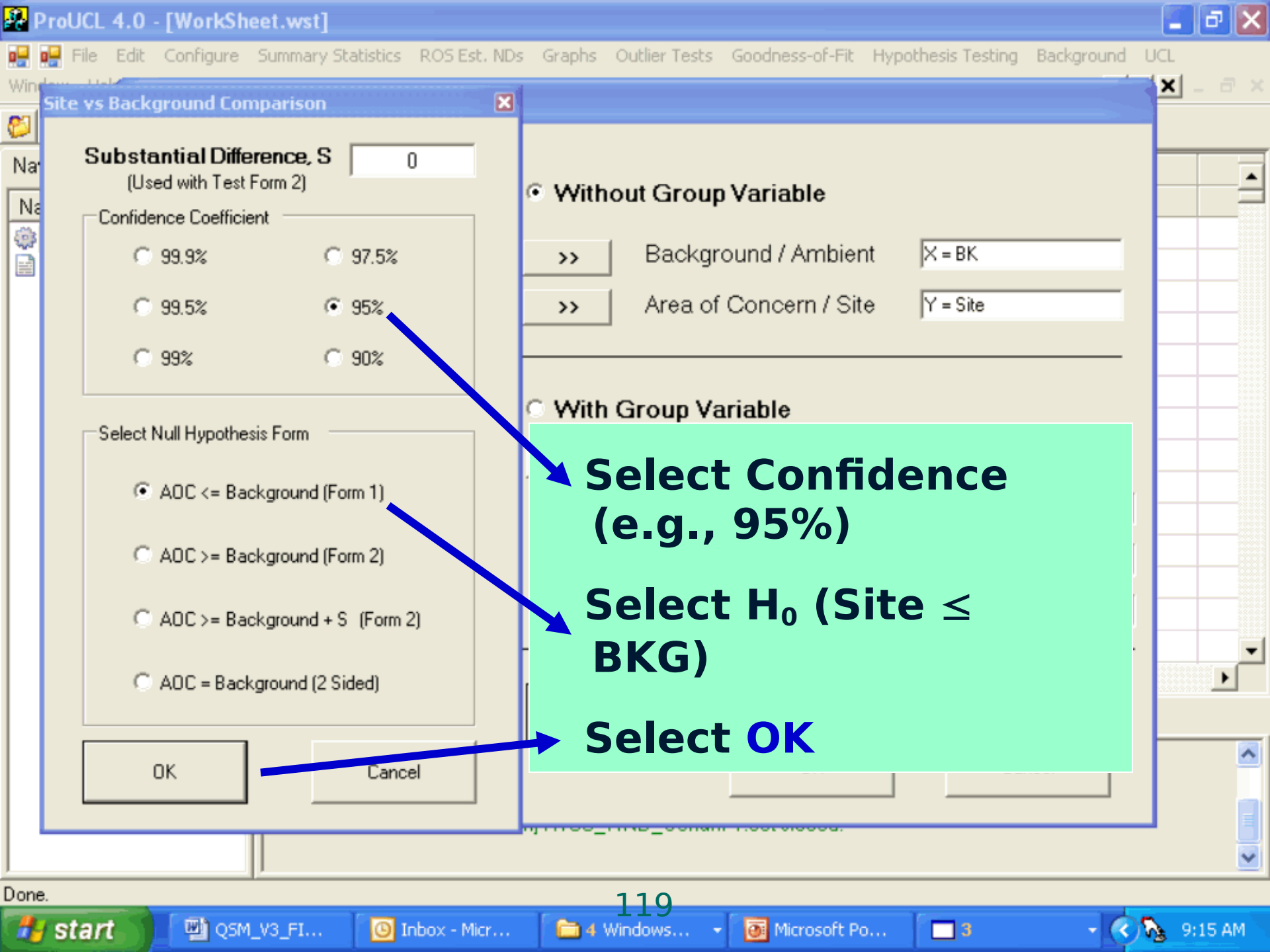

ProUCL 4.0 - [ALLwND_BS.ost]
File Edit Configure Window Help
avigation Panel
Name
WorkSheet.wst
ALLwND_BS.ost
Nonparametric Statistics
Kaplan-Meier (KM) Method
Mean 5.5
SD 2.5
SE of Mean 0.757
95% KM UTL with 90% Coverage 11.03
95% KM Chebyshev UPL 16.84
95% KM UPL (t) 10.17
90% Percentile (z) 8.704
95% Percentile (z) 9.612
99% Percentile (z) 11.32
Output:
95% KM UTL = 11
95% KM UPL = 10
KM = Kaplan-Meier
Log Panel
LOG: 8:14:57 AM >[Information] ALLwND_BS.ost closed!
LOG: 8:15:17 AM >[Information] Generated results!
LOG: 8:17:50 AM >[Information] ALLwND_BS.ost closed!
LOG: 8:35:44 AM >[Information] Generated results!
start
QSM_V3_FI...
Inbox - Micr...
6 Windows...
Microsoft Po...
ProUCL 4.0 -...
8:37 AM

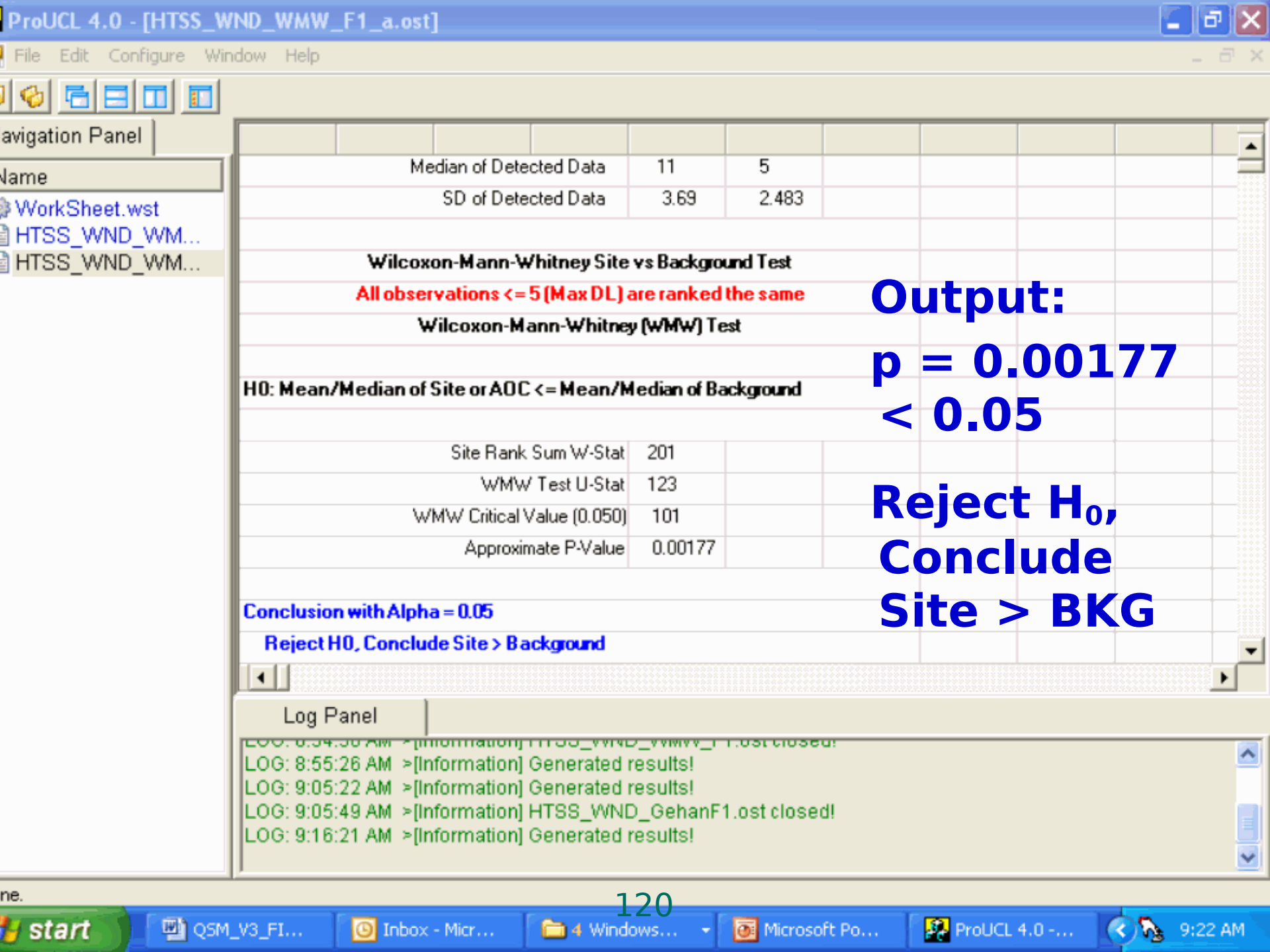

ProUCL 4.0
File Edit Configure Summary Statistics ROS Est. NDs Graphs Outlier Tests Goodness-of-Fit Hypothesis Testing Background UCL Window
avigation Panel
Name
WorkSheet.wst
HTSS_WND_WM...
WorkSheet.wst
0 1 2 3
X = BK d_X = BK Y = Site d_Y = Site
1 1 0 5 0
2 2 1 6 1
3 3 1 7 1
4 4 1 8 1
5 5 1 9 1
6 5 1 10 1
7 5 1 11 1
8 6 1 12 1
9 7 1 13 1
10 8 1 15 1
11 9 1 16 1
12 10 1 17 1
13
Log Panel
LOG: 8:47:27 AM >[Information] ALLwND_BS.ost close
LOG: 8:53:46 AM >[Information] Generated results!
LOG: 8:54:36 AM >[Information] HTSS_WND_WMW_F1
LOG: 8:55:26 AM >[Information] Generated results!
start
QSM_V3_FI...
Inbox - Micr...
6 Windows...
Microsoft Po...
ProUCL 4.0
9:01 AM

To do two-sample hypothesis tests go to menu:

Hypothesis Testing → Two Sample → With NDs → Wilcoxon-Mann-Whitney OR Gehan


ProUCL 4.0 - [WorkSheet.wst]
File Edit Configure Summary Statistics ROS Est. NDs Graphs Outlier Tests Goodness-of-Fit Hypothesis Testing Background UCL
Select Variables
Variables
Name ID Count
X = BK 0 12
Y = Site 2 12
Without Group Variable
>>
Background / Ambient
>>
Area of Concern / Site
With Group Variable
>>
Variable
Group Var
Background / Ambient
Area of Concern / Site
Options
OK
Cancel
Select background and site data sets using >> buttons
Select Options button.


ProUCL 4.0 - [WorkSheet.wst]
File Edit Configure Summary Statistics ROS Est. NDs Graphs Outlier Tests Goodness-of-Fit Hypothesis Testing Background UCL
Site vs Background Comparison
Substantial Difference, S
(Used with Test Form 2)
0
Confidence Coefficient
99.9%
97.5%
99.5%
95%
99%
90%
Select Null Hypothesis Form
AOC <= Background (Form 1)
AOC >= Background (Form 2)
AOC >= Background + S (Form 2)
AOC = Background (2 Sided)
OK
Cancel
Without Group Variable
>>
Background / Ambient
X = BK
>>
Area of Concern / Site
Y = Site
With Group Variable
Select Confidence (e.g., 95%)
Select H0 (Site ≤ BKG)
Select OK
Done.
start
QSM_V3_FI...
Inbox - Micr...
4 Windows...
Microsoft Po...
3
9:15 AM


ProUCL 4.0 - [HTSS_WND_WMW_F1_a.ost]
File Edit Configure Window Help
Navigation Panel
Name
WorkSheet.wst
HTSS_WND_WM...
HTSS_WND_WM...
Median of Detected Data 11 5
SD of Detected Data 3.69 2.483
Wilcoxon-Mann-Whitney Site vs Background Test
All observations <= 5 (Max DL) are ranked the same
Wilcoxon-Mann-Whitney (WMW) Test
H0: Mean/Median of Site or AOC <= Mean/Median of Background
Site Rank Sum W-Stat 201
WMW Test U-Stat 123
WMW Critical Value (0.050) 101
Approximate P-Value 0.00177
Conclusion with Alpha = 0.05
Reject H0, Conclude Site > Background
Output:
p = 0.00177
< 0.05
Reject H0,
Conclude
Site > BKG
Log Panel
LOG: 8:55:26 AM >[Information] Generated results!
LOG: 9:05:22 AM >[Information] Generated results!
LOG: 9:05:49 AM >[Information] HTSS_WND_GehanF1.ost closed!
LOG: 9:16:21 AM >[Information] Generated results!
start
QSM_V3_FI...
Inbox - Micr...
4 Windows...
Microsoft Po...
ProUCL 4.0 -...
9:22 AM

ProUCL Exercise

- Enter results:

  Site: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

  BKG: 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

  Hint: First right click on column 0 to enter Header Name *Site* then on column 1 to enter Header Name *BKG*.

- Do Form 1 test (Wilcoxon) to compare Site with BGK at 95% CL:

  H_0: $\mu_{Site} \leq \mu_{BKG}$, H_1: $\mu_{Site} > \mu_{BG}$

  Determine if H_0 can be rejected.

  Hint: Hypothesis Tests → Two Sample → Full (w/0 NDs) → Wilcoxon-Mann-Whitney

ProUCL Exercise (Continued)

- Do Form 2 test (Wilcoxon) at 95% CL.

  H_0: $\mu_{Site} \geq \mu_{BKG} + S$, H_1: $\mu_{Site} < \mu_{BG} + S$

  Find smallest (positive integer) value of S that results in rejection of H_0.

  Solutions:

  Form 1: Cannot reject H_0

  Form 2: S = 5

"Rules of Thumb" for Using ProUCL

- Select "**With NDs**" menu option unless all results are detects. ProUCL will do non-parametric statistical evaluations as they are more appropriate when there are non-detects.
- Select the "**All**" menu option for most comprehensive statistical evaluati

Using ProUCL (Continued)

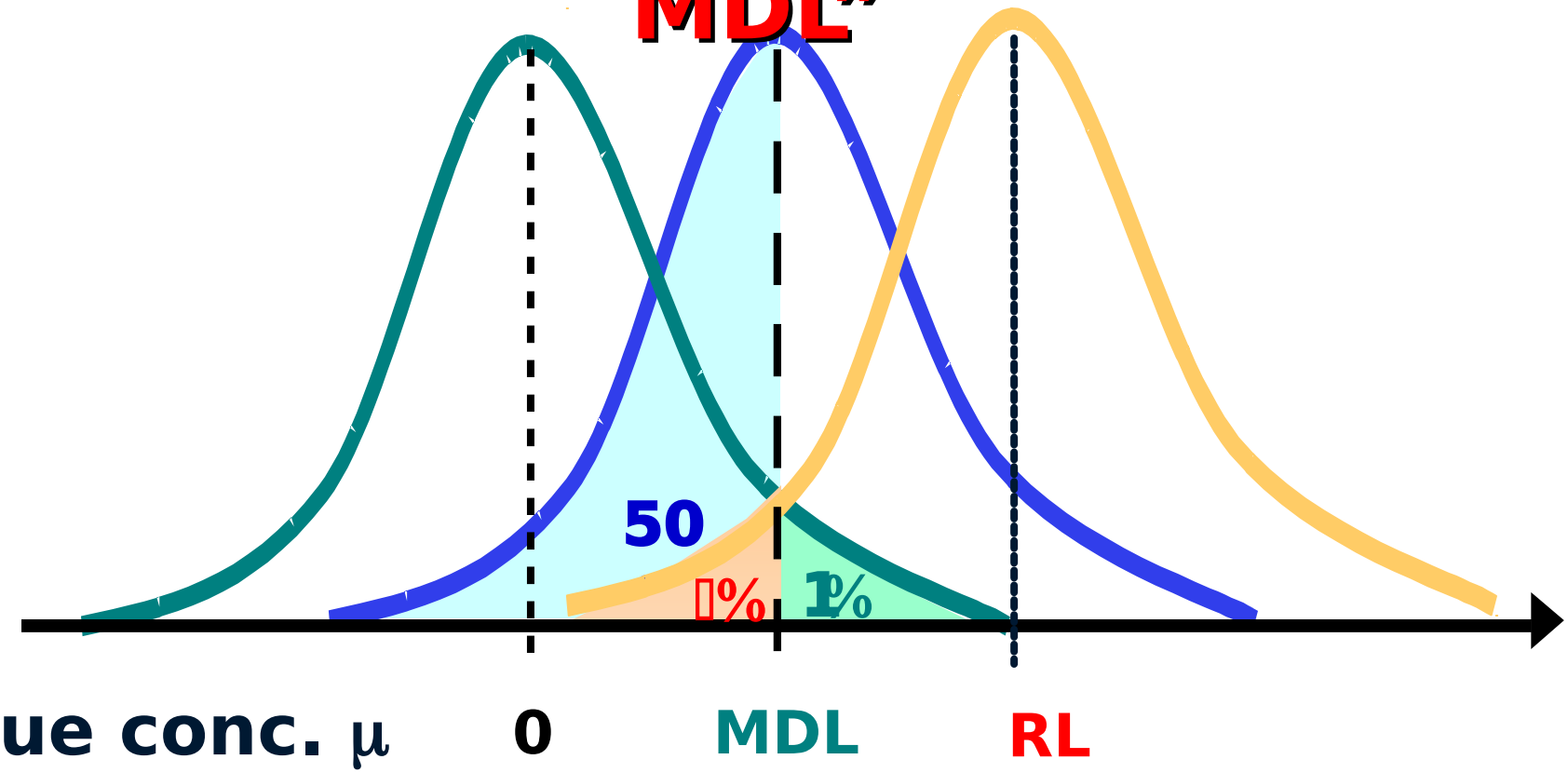
- Give each variable a name (e.g., *X*); enter results down column, using **reporting limits** (RLs) for non-detects.

  Caution: Do not enter method detection limits (MDLs) for non-detects.

- Code detects with 1's and non-detects with 0's in a separate column for each variable (e.g., d_X).

Part 4
Detection and Quantitation Limits

Why non-detects should be reported as "< RL" NOT "< MDL"



Analytical Sensitivity

- **Method detection limit, MDL** – Threshold for confidently (e.g., 99%) reporting detects.
- **Reporting Limit, RL** – Threshold for confidently (e.g., 99%) reporting non-detects.
- **Quantitation Limit, QL** – Smallest conc. at which analyte is detected and goals for accuracy (precision and bias) is met.

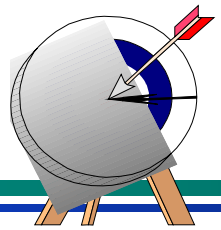
$$MDL < RL \leq QL$$

IUPAC Nomenclature

- International Union of Pure and Applied Chemistry (IUPAC) – International non-governmental standard setting organization for chemical sciences.
  - MDL **Critical value**, L_C $P(X > L_C \mid \mu = 0) = \alpha$
  - RL **Detection limit**, L_D $P(X \leq L_C \mid \mu = L_D) = \beta$
  - QL **Limit of quantification**, L_Q $\sigma_Q / L_Q = k_Q = 0.1$

  Note: %RSD = 10% → Control Limits = 70% - 130%

Recommendations



- Report numerical values for all results if possible (even negative concentrations).
- Otherwise, report detects to MDL and non-detects to RL. Do not report non-detects to MDL.
- Determine RL using low-level standard processed through entire method per batch to demonstrate detection capability at RL.
- Process laboratory control sample (LCS) at QL (rather than mid-calibration range) to demonstrate method performance at QL, where RL $\leq$ QL.

True or False ?

The constituents that are most affected by elevated reporting limits are those that exhibit a low detection frequency (generally less than 5 percent) and that, where detected, are normally present at low levels, near the reporting limit. Therefore, the potential is negligible for false negative results under-representing these constituents or biasing source-term concentrations.

- Excerpt from a RI Report written by Shaw Environmental

Example

- 78 surface soil grabs analyzed for 2, 6 – DNT. 1 detect at 0.18 J mg/kg (RL = QL = 0.5 mg/kg).

$HQ_{screen} = MDC / ESV = 5.5 > 1$

HQ_{screen} = Screening-level Hazard Quotient

MDC = Maximum Detected Concentration

ESV = Ecological Screening Value

- 2, 6-DNT identified as a COPEC (chemical of potential ecological).

Should DNT be eliminated as a COPEC?

…Several COPECs were eliminated based on low FODs [frequency of detections]*…COPECs eliminated from further consideration based on low FODs include…2,6-dinitrotoluene* [2, 6-DNT FOD = 1/78 x 100 = 1.3%]

- ESV = 0.0328 mg/kg << RL = 0.5 mg/kg.
- The non-detects do not defensibly demonstrate that DNT < 0.0328 mg/kg !
- $HQ_{screen} \leq 0.5$ mg/kg/0.0328 mg/kg ≈ 20

True or False ?

The constituents that are most affected by elevated reporting limits are those that exhibit a low detection frequency (generally less than 5 percent) and that, where detected, are normally present at low levels, near the reporting limit. Therefore, the potential is negligible for false negative results under-representing these constituents or biasing source-term concentrations.

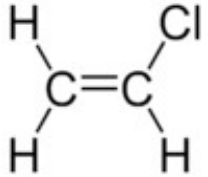
- Excerpt from a RI Report written by Shaw Environmental

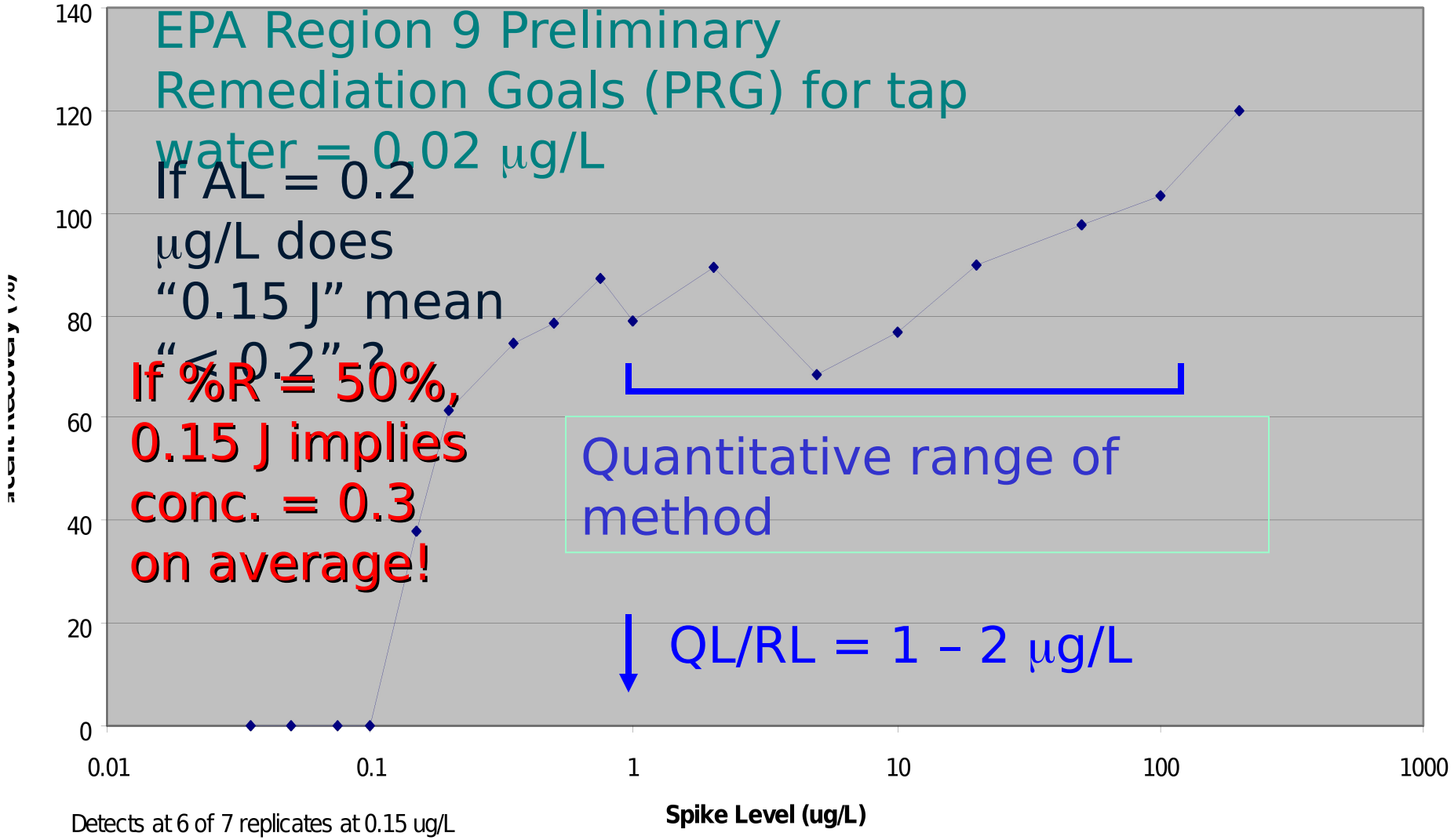
FALSE ! Low frequency of detects (e.g., < 5%) is likely if RL > action level (AL)

Meeting Measure Quality Objectives (MQOs) for Sensitivity

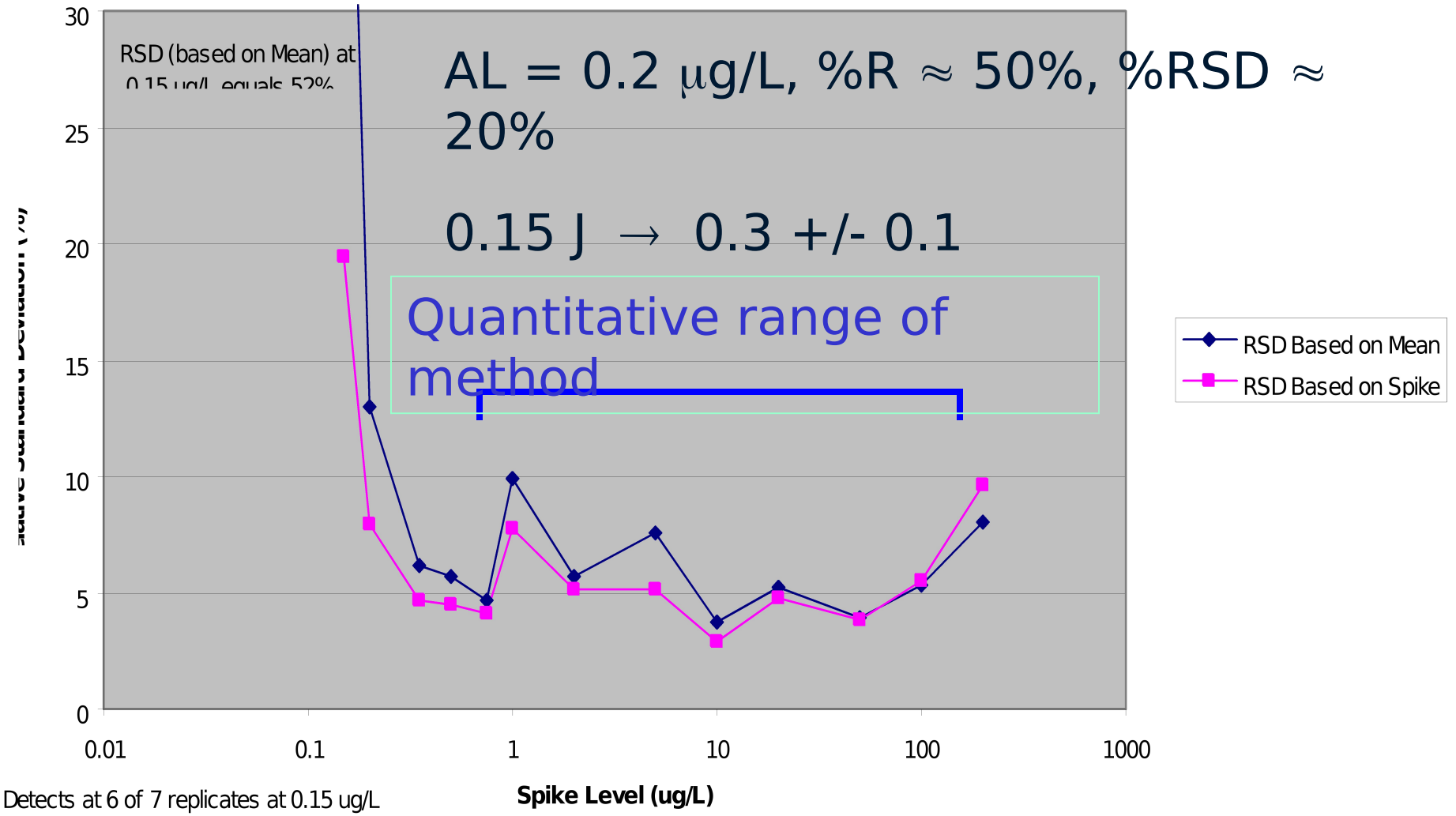
- For non-detects to be usable, the RL must be less than the action level (AL). FNs cannot be defensibly ruled out when AL < RL.
- For detects to be usable, QL must be < AL.
  - Detects < QL reliably only show concentration > 0. They are not quantitative. Example: If RL = 0.5 mg/kg for 2,6-DNT, “0.18 J mg/kg” means “> 0”.
  - If AL < QL, J-qualified detects are not usable for demonstrating contamination is above or below the AL.

Method 524.2
VOCs by GC/MS

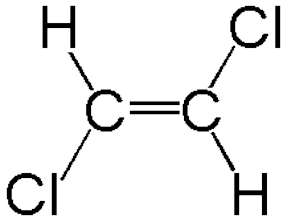




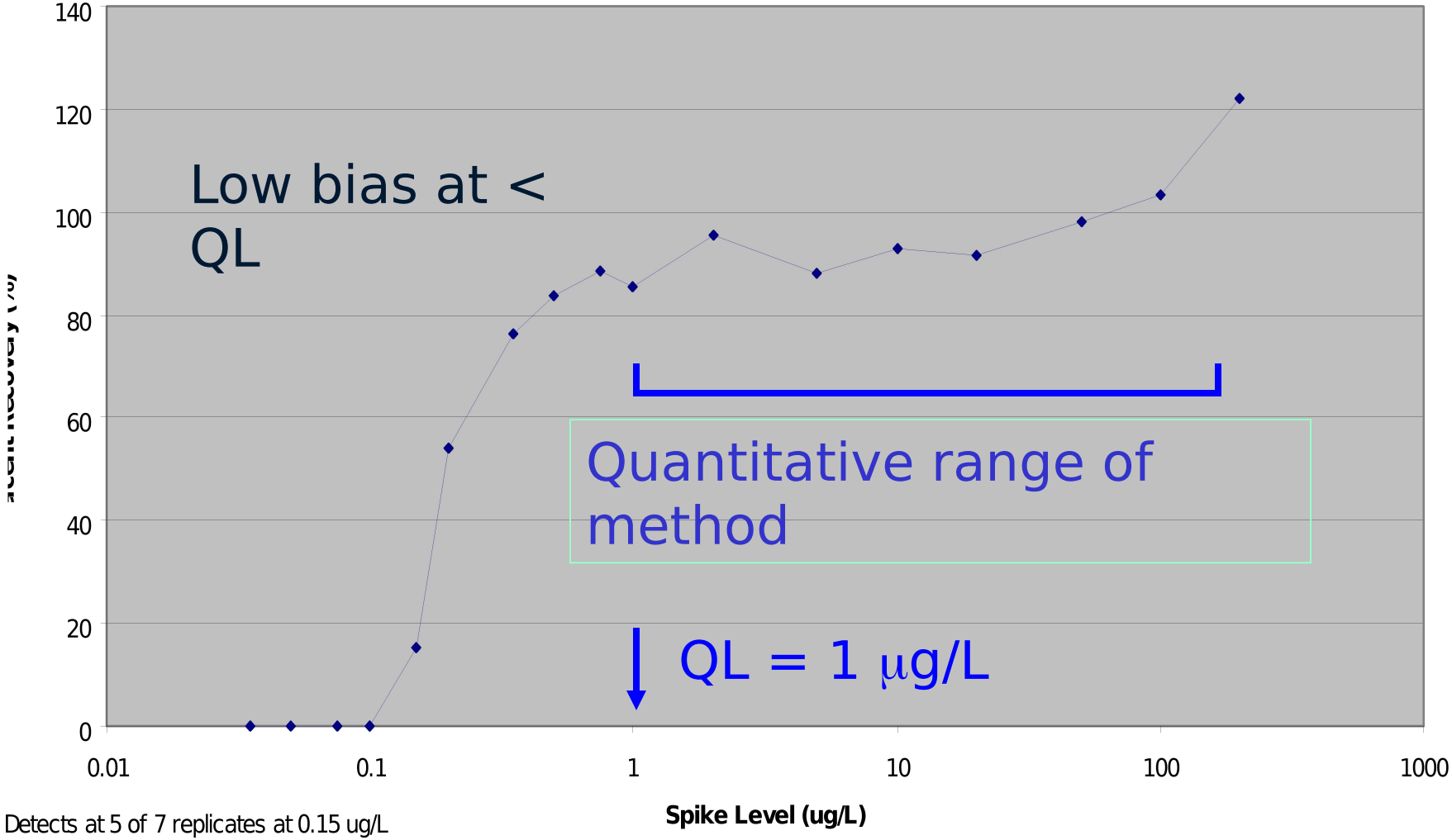
RSD vs. Concentration
Vinyl Chloride



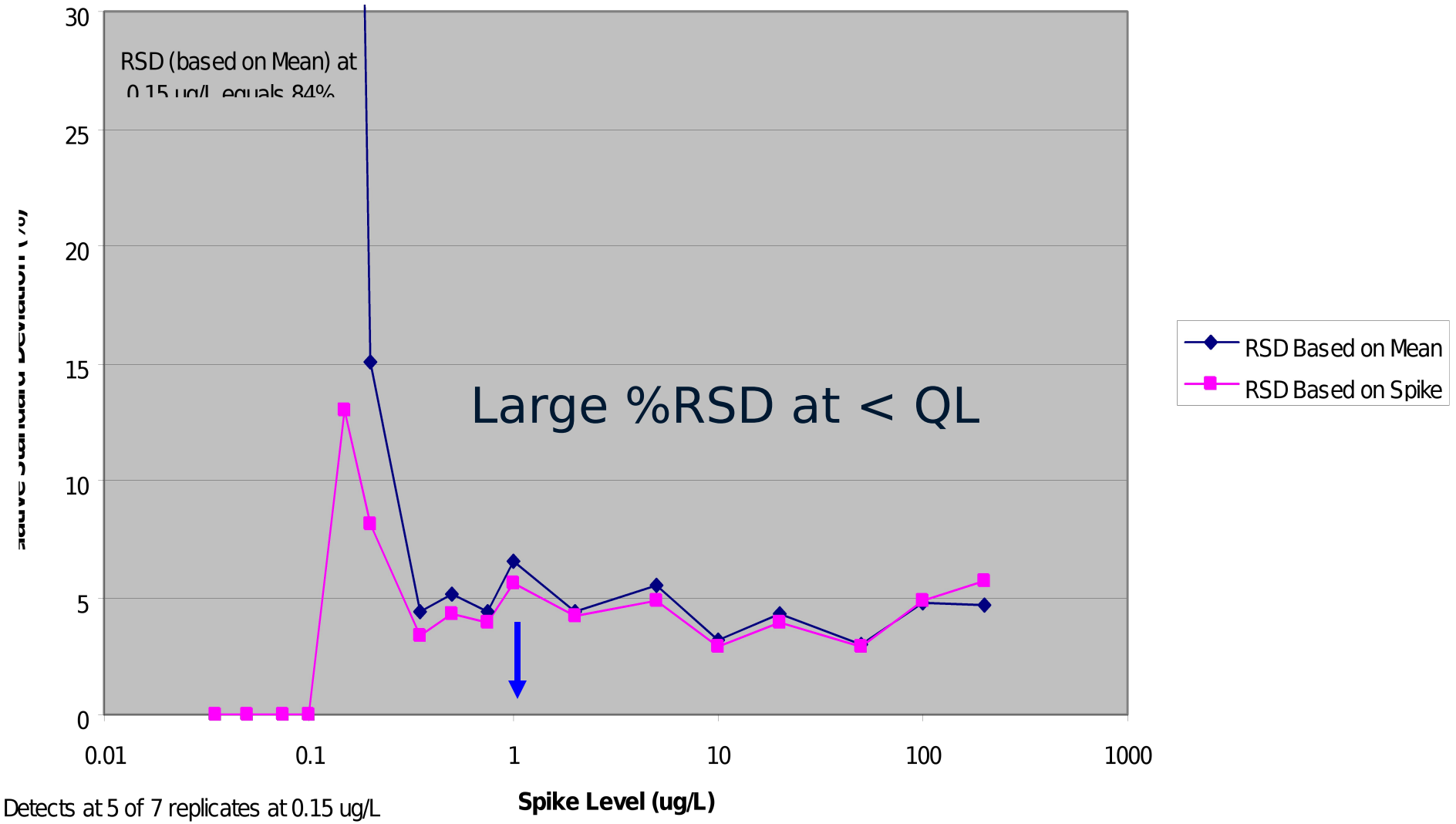
Detects at 6 of 7 replicates at 0.15 ug/L



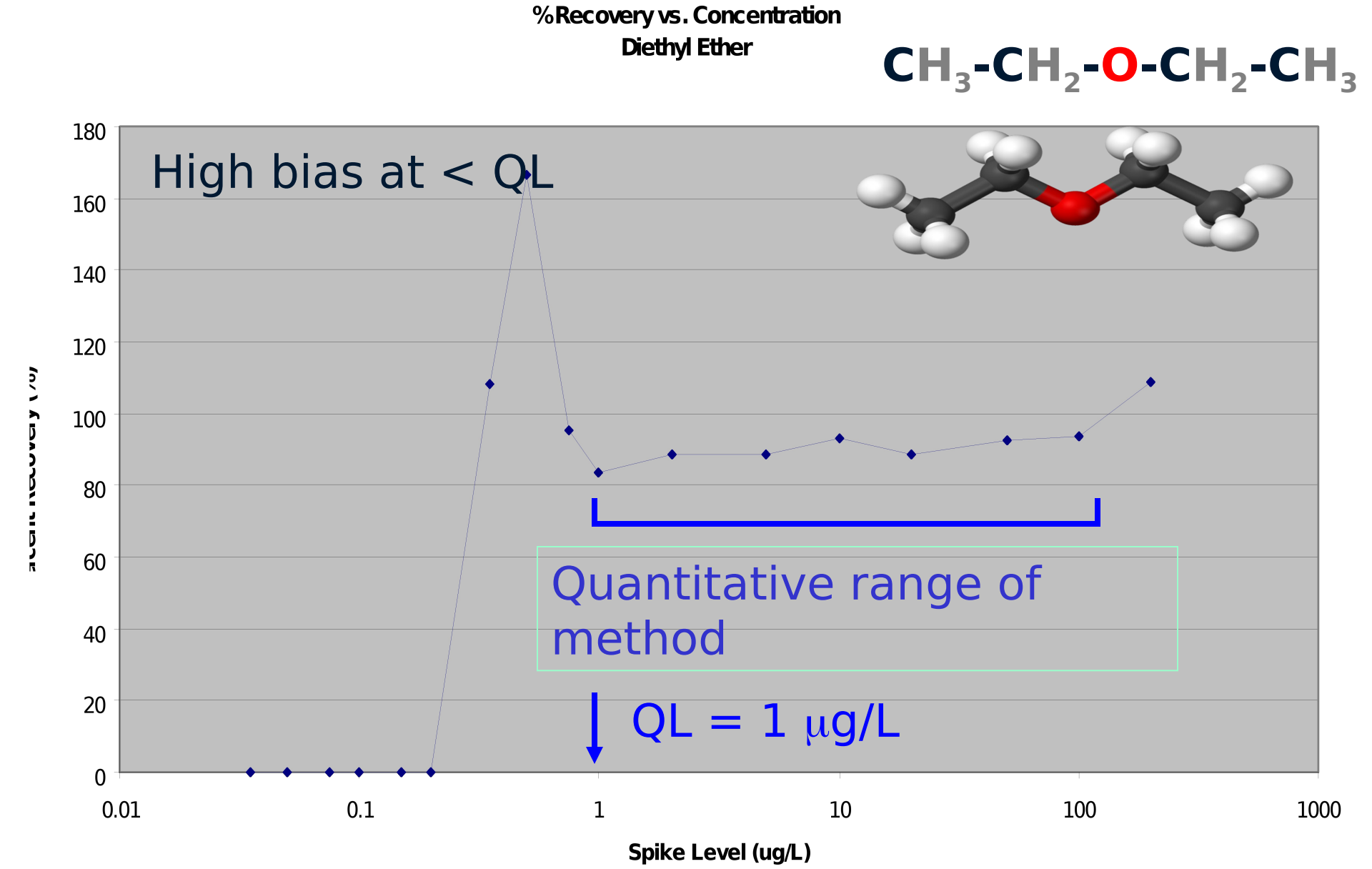
%Recovery vs. Concentration
trans-1,2-Dichloroethene

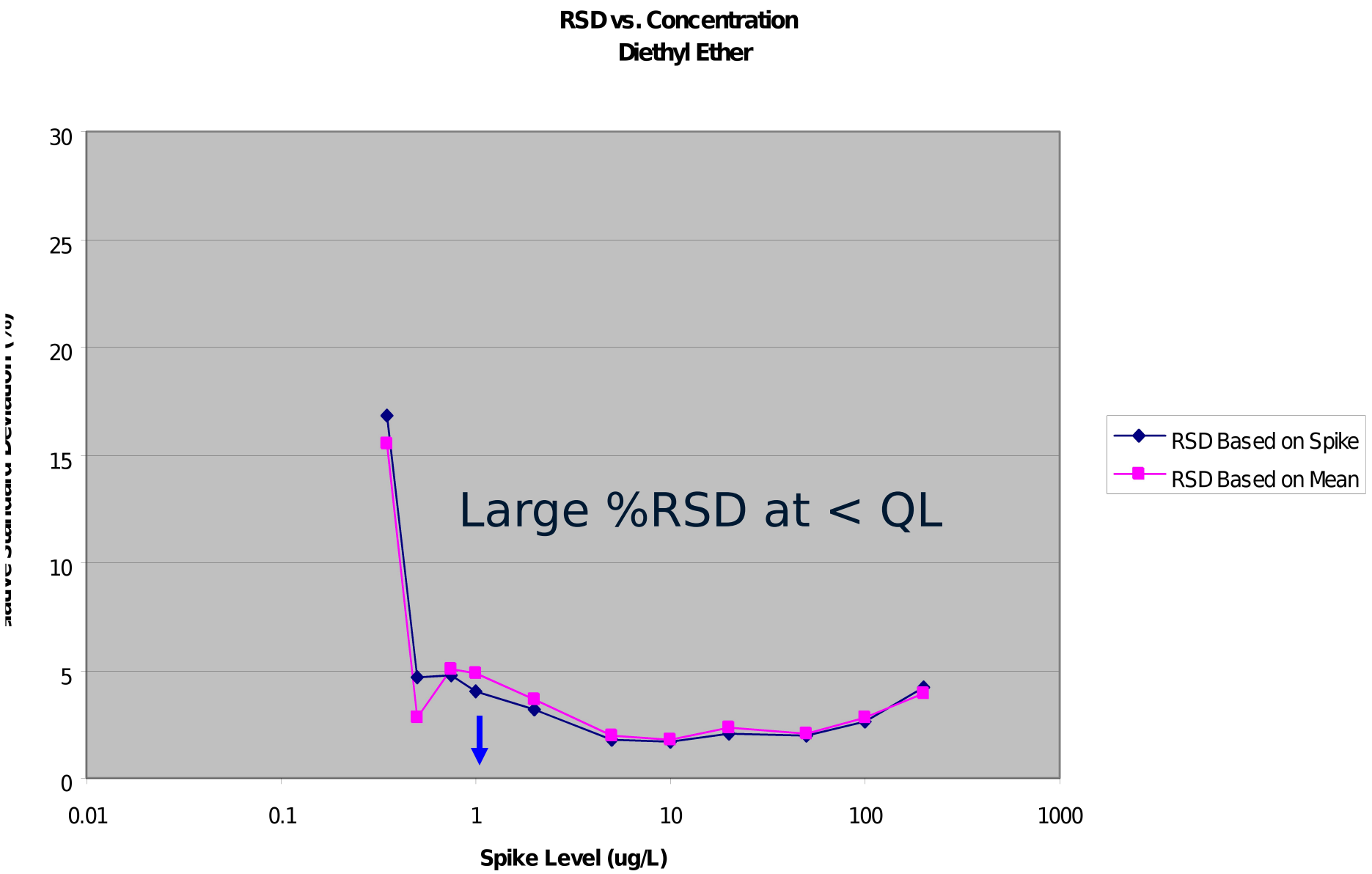


Detects at 5 of 7 replicates at 0.15 ug/L



Detects at 5 of 7 replicates at 0.15 ug/L


%Recovery vs. Concentration
Diethyl Ether
CH_3-CH_2-O-CH_2-CH_3
High bias at < QL
Quantitative range of method
QL = 1 µg/L
180
160
140
120
100
80
60
40
20
0
0.01
0.1
1
10
100
1000
Spike Level (ug/L)


RSD vs. Concentration
Diethyl Ether
Relative Standard Deviation (%)
30
25
20
15
10
5
0
0.01
0.1
1
10
100
1000
Spike Level (ug/L)
Large %RSD at < QL
RSD Based on Spike
RSD Based on Mean

Part 5.0 Qualitative Evaluation of Trends: Times Series Plots

Long-Term Monitoring Groundwater Data for 5-Year Review

- Objective: Determine if concentrations of chlorinated VOCs in study area groundwater (GW) water wells are decreasing or increasing.

- Decision Input (Data): Multiple rounds of yearly or quarterly data from a number of study area GW wells.

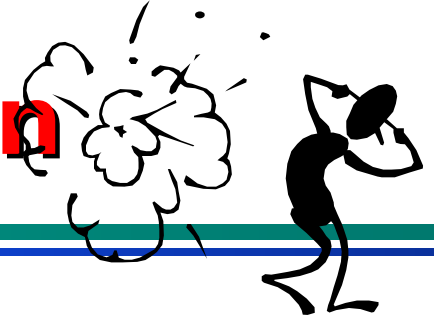
GW TCE Concentrations (µg/L)

Time	MW-1	MW-2
Oct-99	250	6800
Dec-00	280	4500
J an-01	327	3580
J an-02	1360	6160
J an-03	445	3300
J ul-03	171	2960
Apr-05	440	2200

Evaluation:

"TCE in MW-1 increased from Oct-99 to Jan-02, then started to decrease after Jan-02…"

Problem with Evaluation



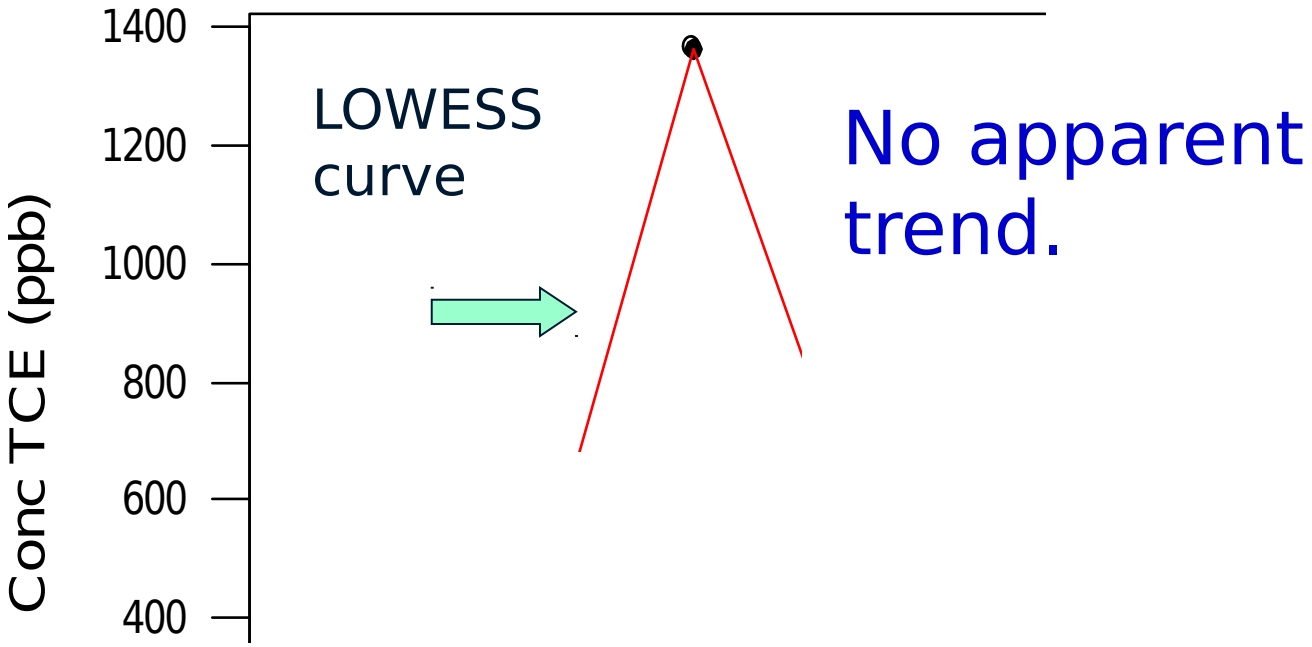
- Measured TCE concentrations are changing but are conditions in aquifer actually changing? Variability could be “noise” (e.g., spatial heterogeneity or random temporal changes).

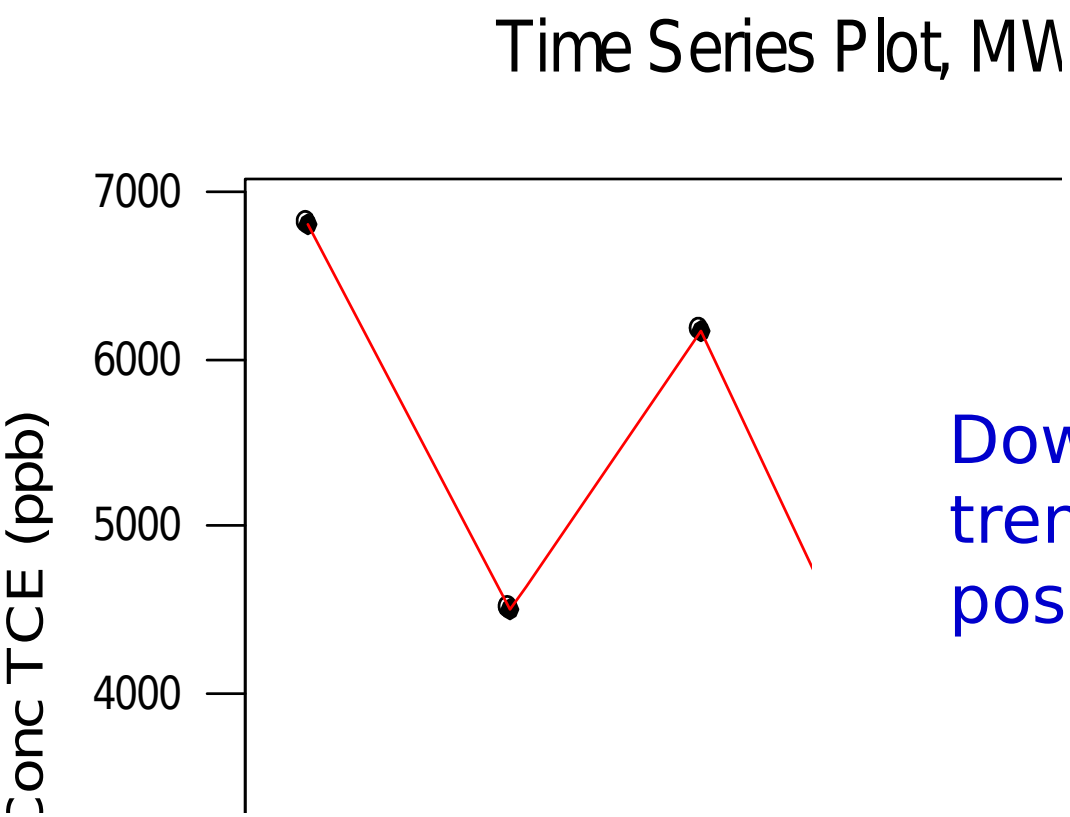
- A simple summary of how individual measured values change is typically of little or no value. *The set of measurements must be evaluated as a whole.*

Times Series Plots

- Scatter (X-Y) plot where *X* = time and *Y* is any variable (usually concentration).
- Advantage: Large data set can be readily evaluated for temporal trends.
- Disadvantage: Subjective nature of qualitative visual evaluation

Times Series (Scatter) Plot

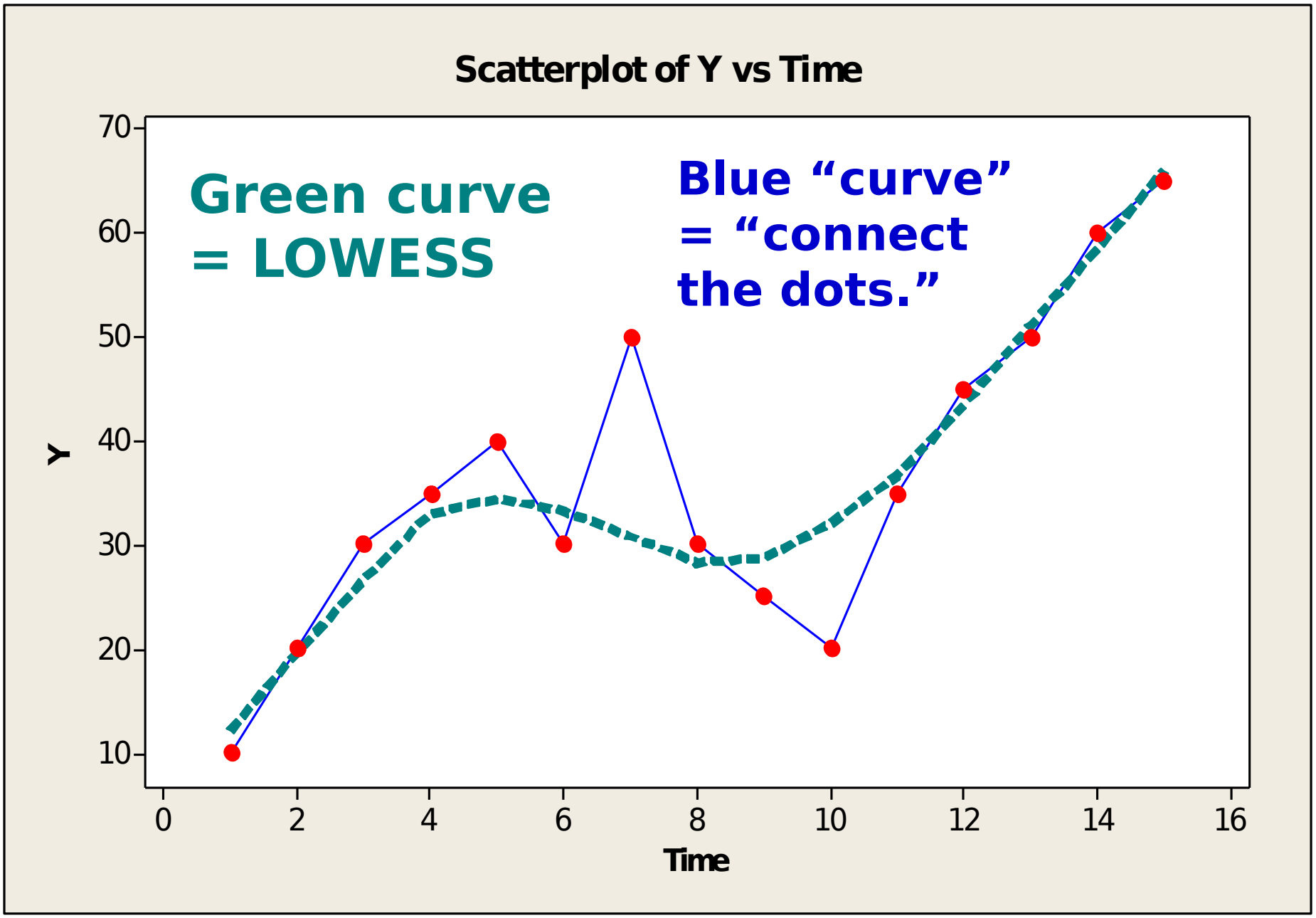




Downward trend possible.

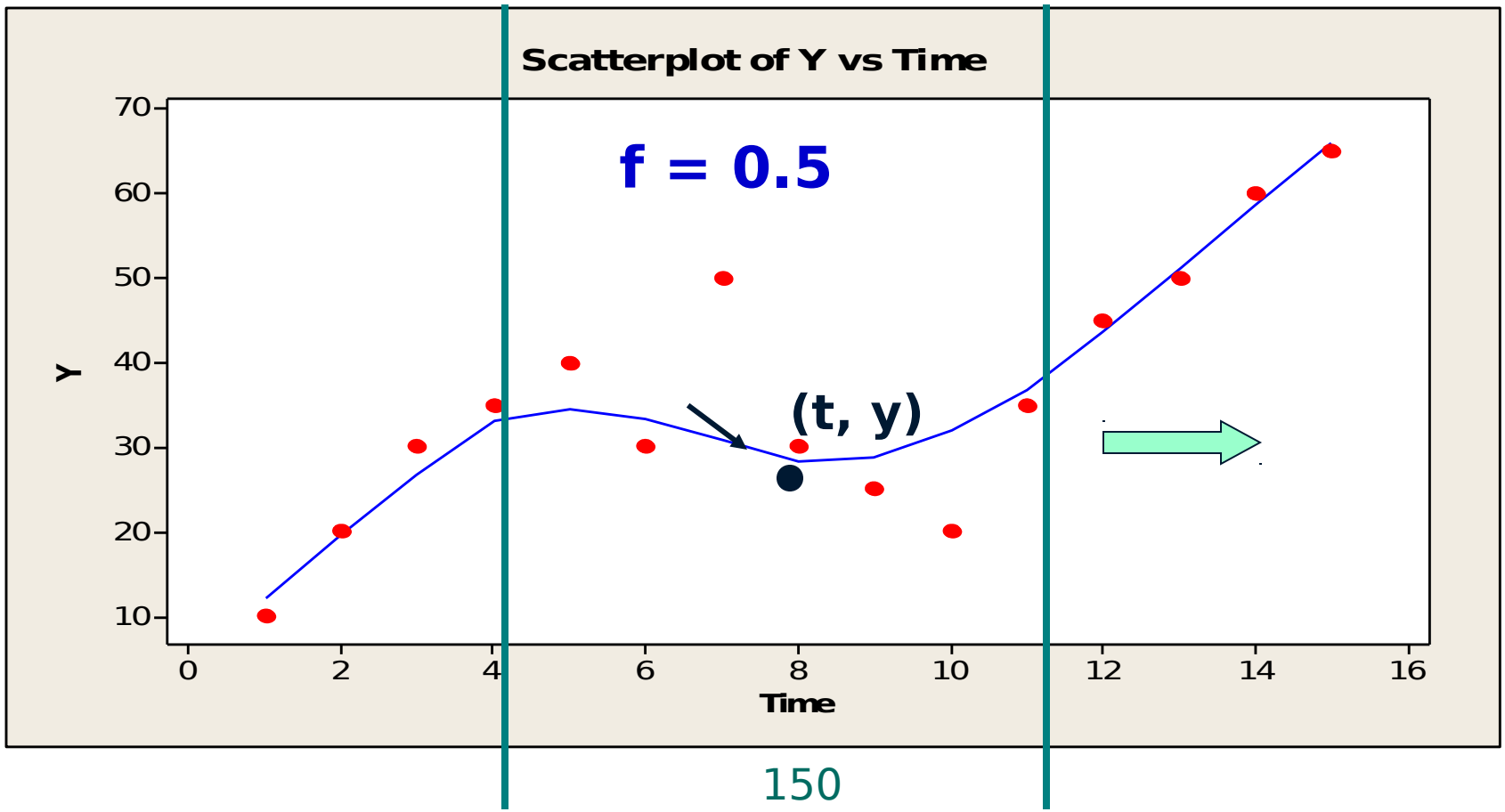
LOWESS

- **LO**cally **WE**ighted **S**catterplot **S**moother**:** Reduces “noise” in time series plots using a computationally intensive weighted regression “smoothing” algorithm to generate a curve.
- Supports qualitative evaluations (e.g., of trends).
- Most useful for moderate to large sample sizes when the changes are not rapid.


Scatterplot of Y vs Time
Green curve
= LOWESS
Blue “curve”
= “connect
the dots.”
Y
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16
Time

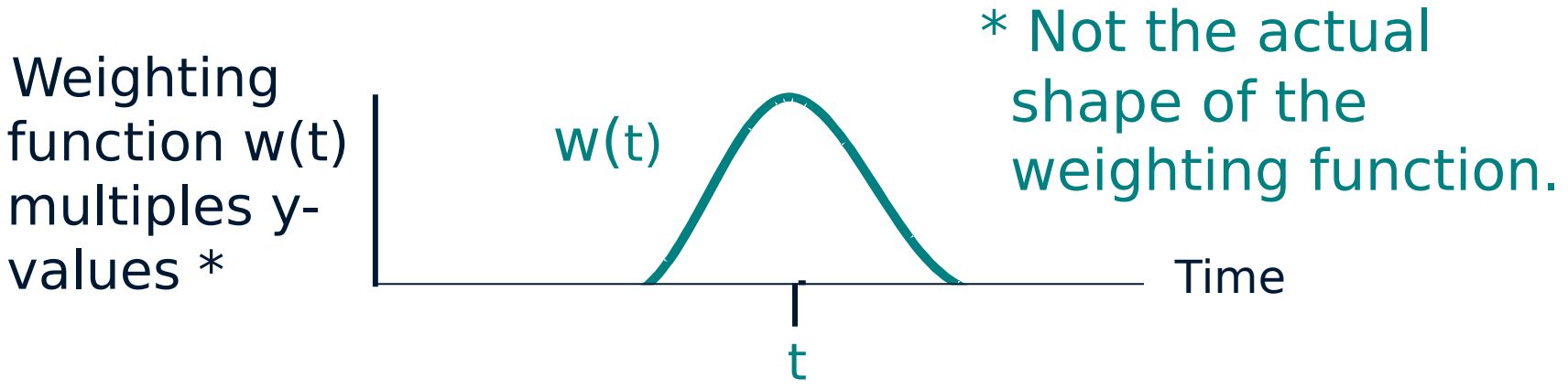
How LOWESS works

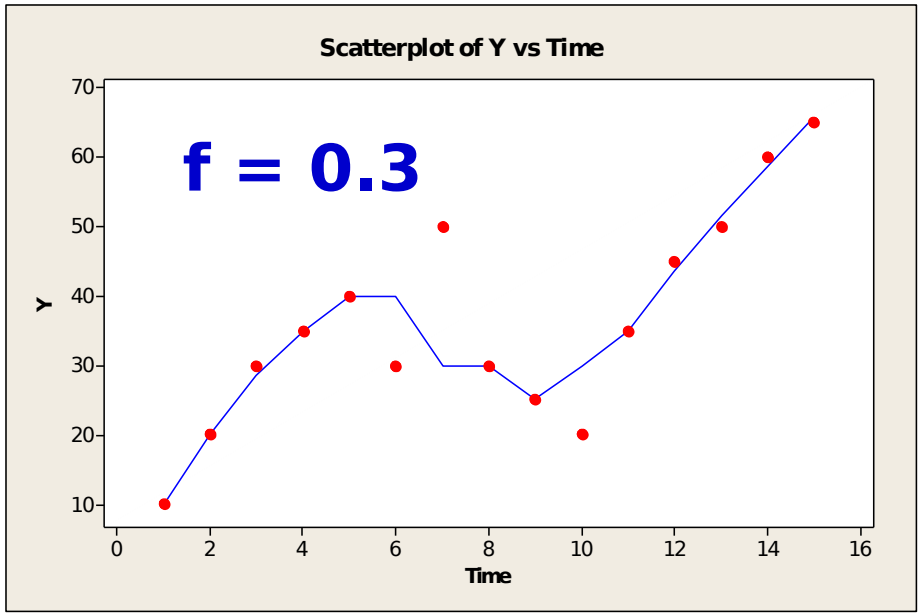
- For each point (t, y), selects some fraction f (0 ≤ f ≤ 1) of total points in “window” centered on t.

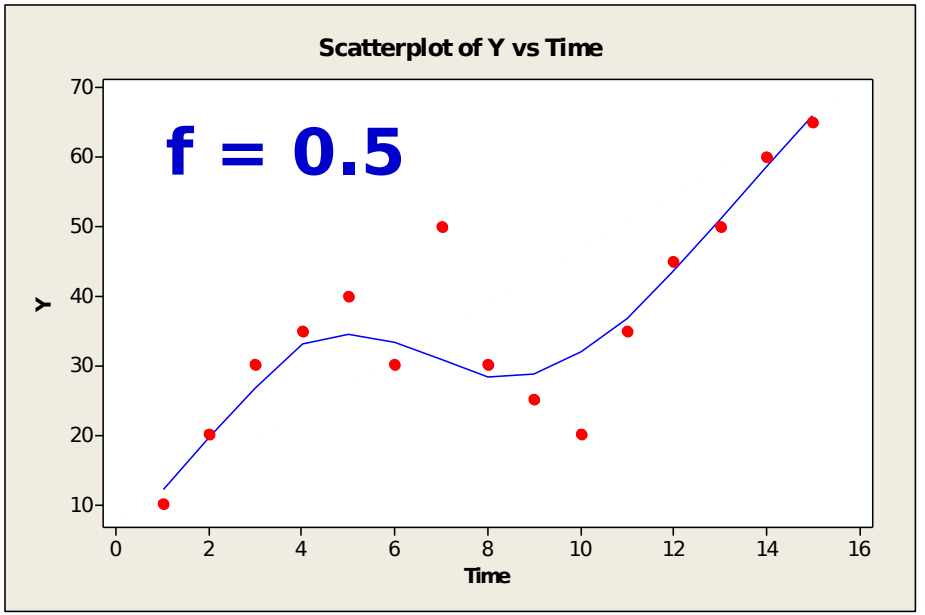


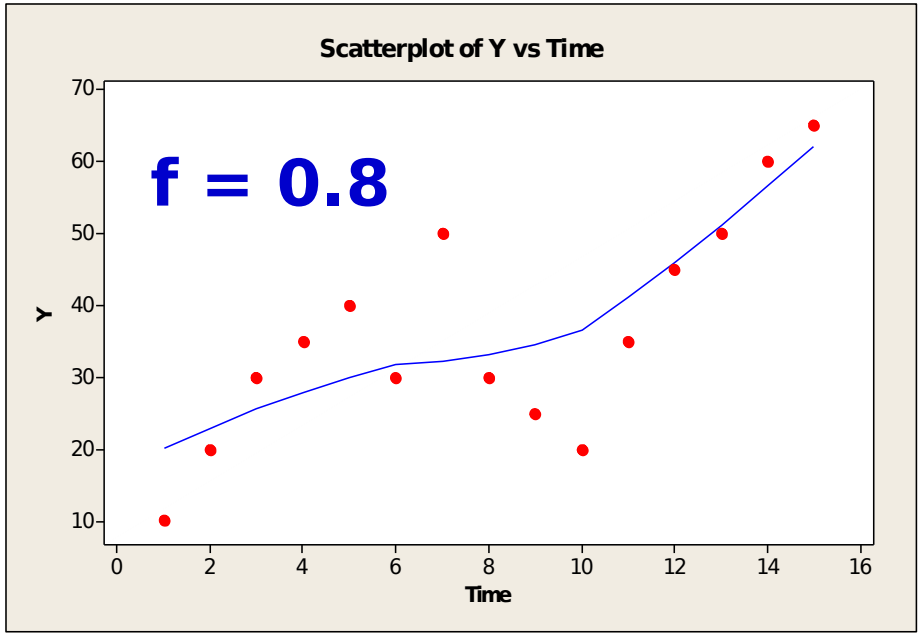
LOWESS Algorithm

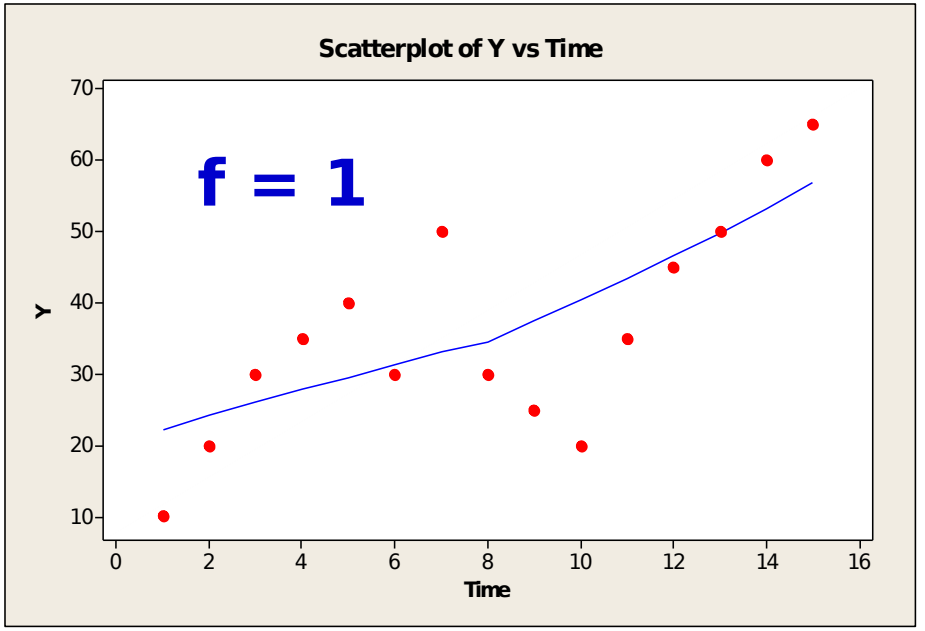
- The most weight is given to points in window closest to t (see figure below). Weight also depends on difference between observed and calculated values (using iterative procedure); outliers given smaller weights. “Smoothing” increases as user increases f.



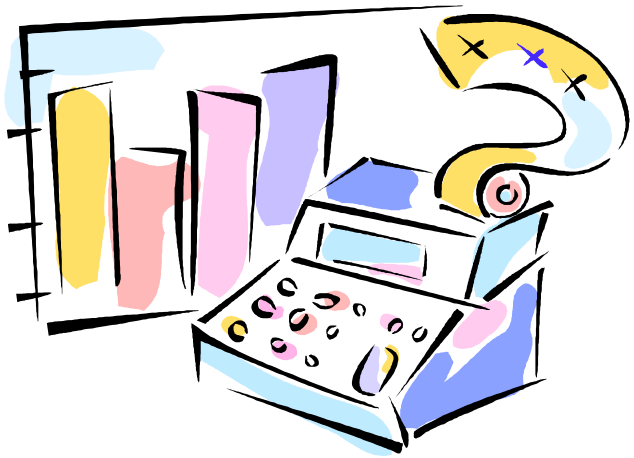

Scatterplot of Y vs Time
f = 0.3
Y
Time
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16


Scatterplot of Y vs Time
f = 0.5
Y
Time
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16

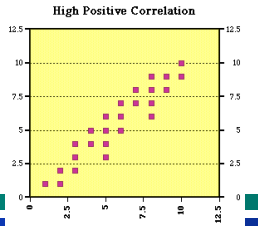

Scatterplot of Y vs Time
f = 0.8
Y
Time
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16


Scatterplot of Y vs Time
f = 1
Y
Time
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16

Part 5.1
Correlation & Quantitative Evaluation of Simple Trends



Correlation



- **Correlation coefficient**: Measures degree of association between two variables *X* and *Y* (i.e., degree to which *X* changes when *Y* changes).
  - Question: Splits samples are taken and analyzed using a field and fixed laboratory method. The field results (*Y*) are highly correlated with the lab results (*X*). Does this demonstrate the field method agrees with the laboratory method?

NO! Correlation ≠ Agreement. Correlation measures how *X* and *Y* **change** (e.g., not the differences between X and *Y*). Example: *X* = {1, 2, 3} and *Y* = {10, 20, 30} are perfectly correlated but disagree.

There are different types of correlation coefficients that share common properties

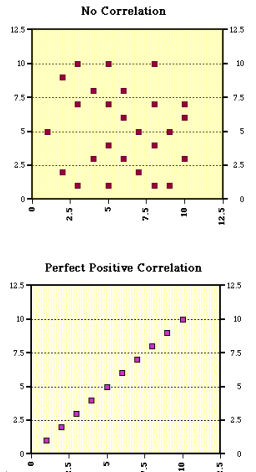
- $-1 \leq \gamma \leq 1$. $|\gamma|$ measures degree of association:

$\gamma = 0$ No relationship

$|\gamma| < 0.5$ "Weak"

$0.75 < |\gamma| < 0.90$ "Moderate"

$0.95 < |\gamma| < 1$ "Strong"



- Sign of γ measures "direction" of association:

$\gamma > 0$ Positive correlation (X increases, Y increases)

$\gamma > 0$ Negative correlation (X increases, Y decreases)

Correlation Coefficients

- **Population correlation coefficient**, γ (which is typically unknown) is estimated by the **sample correlation coefficient**, γ_s; calculated from **paired** measurements: (x_1, y_1), (x_2, y_2).... (x_n, y_n).
  - n = number of pairs
- It is unlikely the sample correlation coefficient γ_s will be exactly zero even when the population correlation coefficient $\gamma = 0$ (i.e., when there is no correlation).

Hypothesis Test for Correlation

- Hypothesis test is done to determine if γ_s is significantly different from zero ($\gamma \neq 0$)

$$H_0: \gamma = 0, \;\; H_1: \gamma \neq 0 \;\; (\gamma > 0 \text{ or } \gamma < 0)$$

The larger $|\gamma_s|$, the smaller the p-value (likelihood a correlation coefficient as large as γ_s will be observed by chance when $\gamma = 0$). Nature of test depends on type of correlation coefficient used.

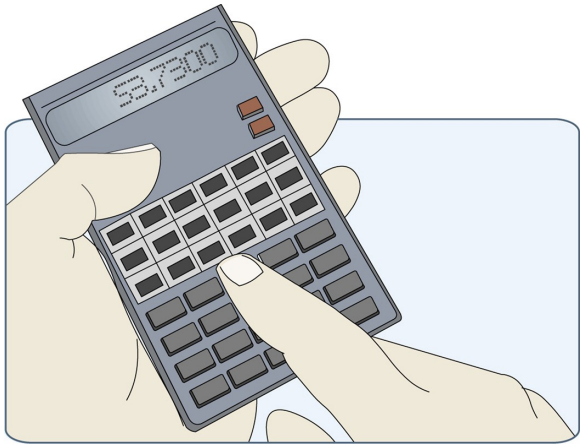
Correlation Coefficient, Pearson's r

$$r = \frac{\Sigma_i x_i y_i - n \bar{x} \bar{y}}{(n-1) s_X s_Y} \qquad (i = 1, 2, \ldots, n)$$

$$s_X = (\Sigma_i x_i^2 - n \bar{x}^2)^{1/2} / (n - 1)$$

$$s_Y = (\Sigma_i y_i^2 - n \bar{y}^2)^{1/2} / (n - 1)$$

$$\bar{x} = \Sigma_i x_i / n, \quad \bar{y} = \Sigma_i y_i / n$$



Hypotheses Tests for r

Calculate test statistic: $t = \dfrac{r}{\sqrt{\dfrac{1- r^2}{n- 2}}}$

Why is it “R” and not “r”?

H_0: $R \leq 0$, H_1: $R > 0$: Upward trend if $t > t_{1-\alpha\ ,\ n\ -2}$

H_0: $R \geq 0$, H_1: $R < 0$: Downward trend if $t < -\ t_{1-\alpha,\ n\ -2}$

H_0: $R = 0$, H_1: $R \neq 0$: Trend if $|t\ | > t_{1-\alpha/2,\ n\ -\ 2}$

Find critical values in table.

Example

n = 10, r = 0.7, 2-tailed test at 90% CL (α = 0.10)

H_0: R = 0, H_1: R ≠ 0:

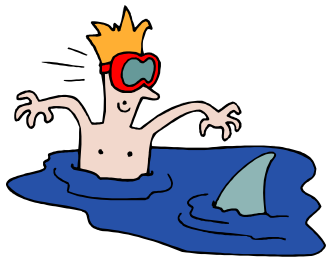
Conclude trend exists if $|t| > t_{1-\alpha/2,\, n-2} = t_{0.95,\, 8} = 1.86$.

$$|t| = \left| \frac{r}{\sqrt{\frac{1-r^2}{n-2}}} \right| = \frac{0.7}{\sqrt{\frac{1-0.7^2}{10-2}}} = 10.98 > 1.86$$

Trend exists (R ≠ 0) with at least 90% confidence

Properties of Pearson's r

- Parametric correlation coefficient that measures **linear** association:



  - **Very sensitive to extreme values**
  - **Does not handle non-detects.**
  - Not optimal for non-linear relationships or variables that are not normal (though is likely acceptable unless deviations are severe).
  - Invariant under linear transformations ($X \rightarrow a\,X + b$) but not non-linear transformations (e.g., r [X, Y] $\neq$ r [log(X), log(Y)]).

Kendall's tau, τ

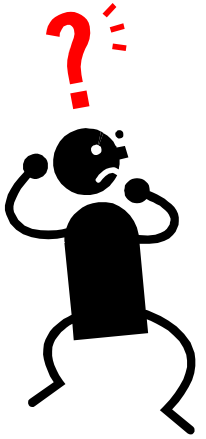
- Non-parametric correlation coefficient that addresses many of the problems with Pearson's r:
  - **Robust** (insensitive) to extreme values
  - Robust to non-detects.
  - Appropriate for non-linear relationships and normality is not required.
  - Invariant under monotonic non-linear transformations (e.g., is unaffected by log transformation)

Pearson's r versus Kendall's τ

Recommended for:	r	τ
extreme values (outliers)	No	Yes
non-detects	No	Yes
non-linearity	No	Yes
non-normality	No	Yes

Kendall's τ Measures Monotonic Association

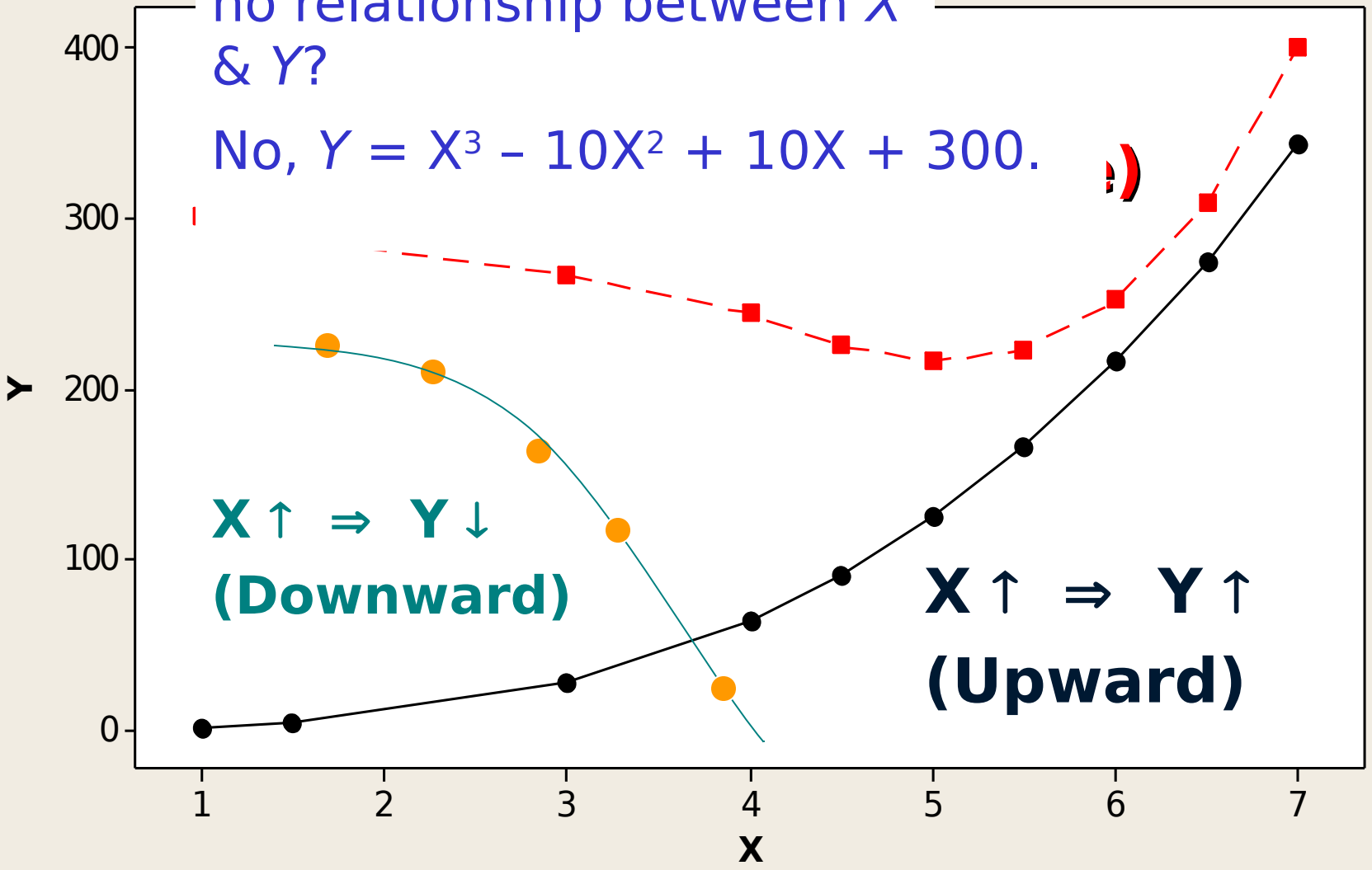
Mono Who?



- **Monotonic** means order is preserved.
  - Increasing monotonic: $x_2 > x_1 \rightarrow y_2 > y_1$
  - Decreasing monotonic: $x_2 > x_1 \rightarrow y_2 < y_1$

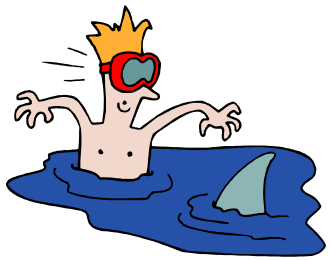
Does this mean there is no relationship between X & Y?

No, $Y = X^3 - 10X^2 + 10X + 300$.



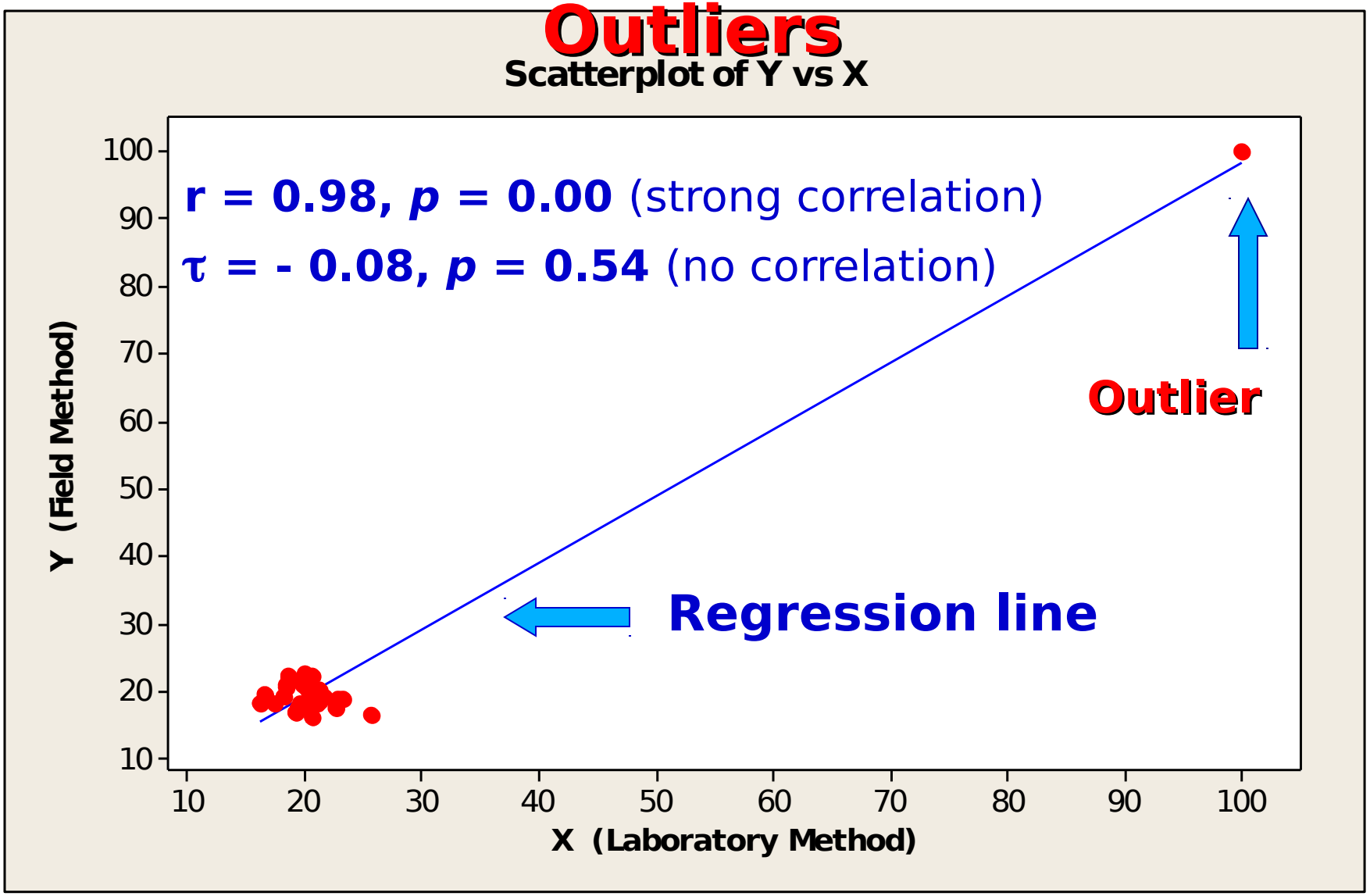
Properties of Pearson's r

- Parametric correlation coefficient that measures **linear** association:

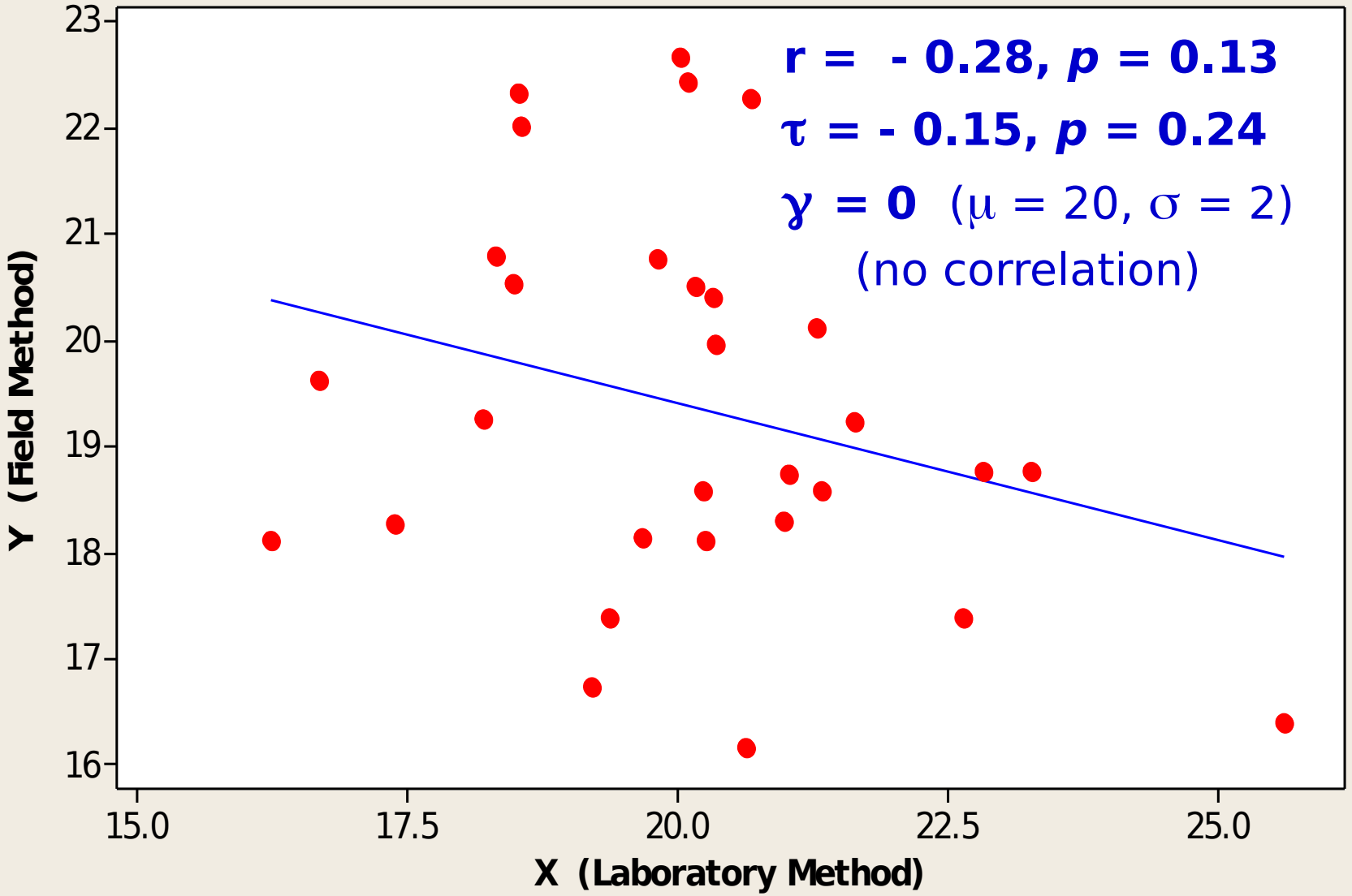


  - **Very sensitive to extreme values**
  - Does not handle non-detects.
  - Not optimal for non-linear relationships or variables that are not normal (though is likely acceptable unless deviations are severe).
  - Invariant under linear transformations ($X \rightarrow a\,X + b$) but not non-linear transformations (e.g., r [X, Y] $\neq$ r [log(X), log(Y)]).

Pearson's r, Kendall's τ and Outliers

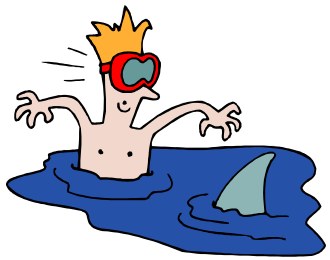


Outlier Removed



Properties of Pearson's r

- Parametric correlation coefficient that measures **linear** association:



  - Very sensitive to extreme values
  - **Does not handle non-detects.**
  - Not optimal for non-linear relationships or variables that are not normal (though is likely acceptable unless deviations are severe).
  - Invariant under linear transformations ($X \rightarrow a\,X + b$) but not non-linear transformations (e.g., r [X, Y] $\neq$ r [log(X), log(Y)]).

Data Sets with Non-detects (NDs)

- **Censored data:** Non-detects (NDs).
- **Censoring limit**: RL for non-detects.
- **Substitution Method (SM)**: Substituting some multiple of censoring limit (e.g.,RL/2) as a numerical value for NDs.

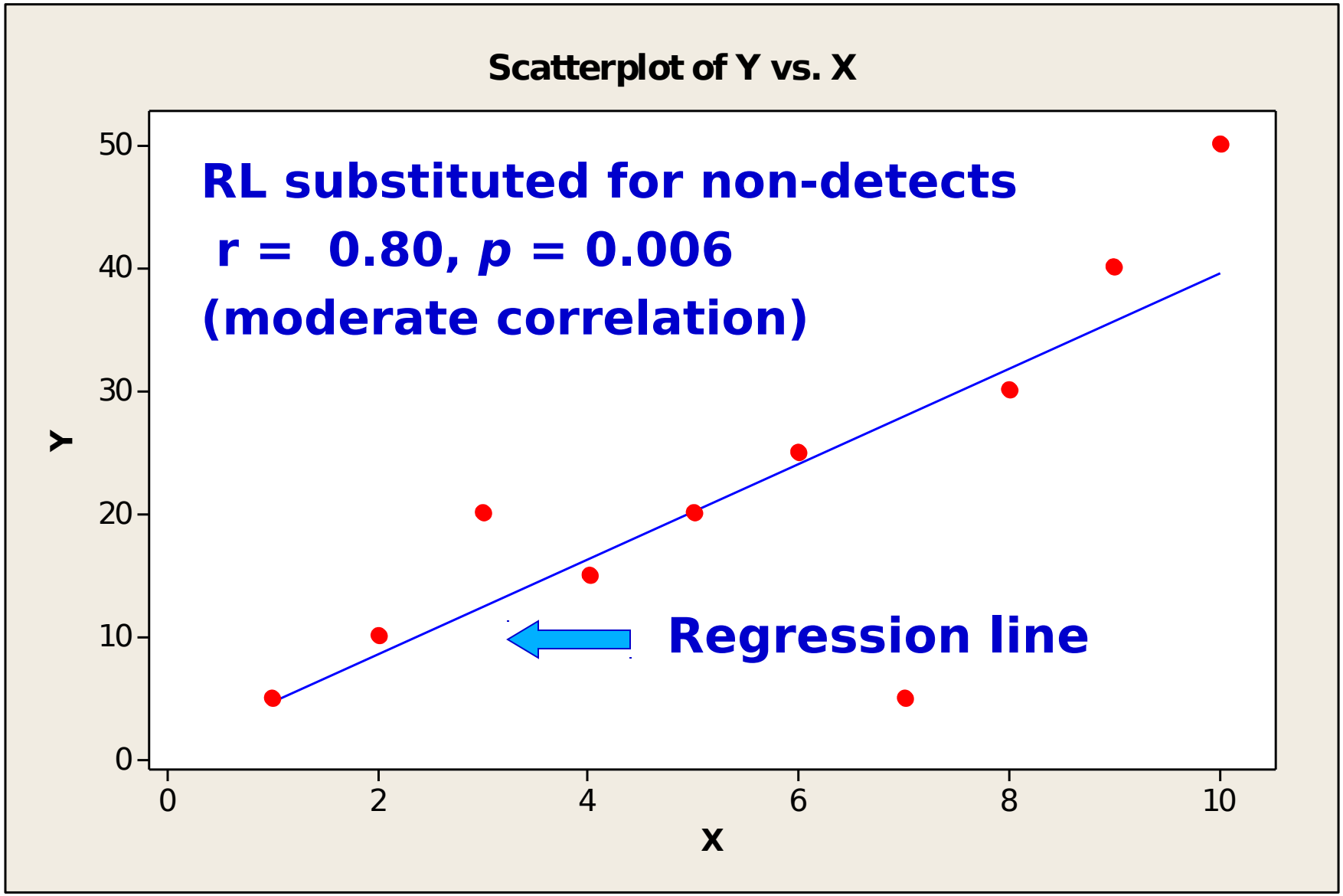
Risk Assessment Guidance for Superfund (1989):

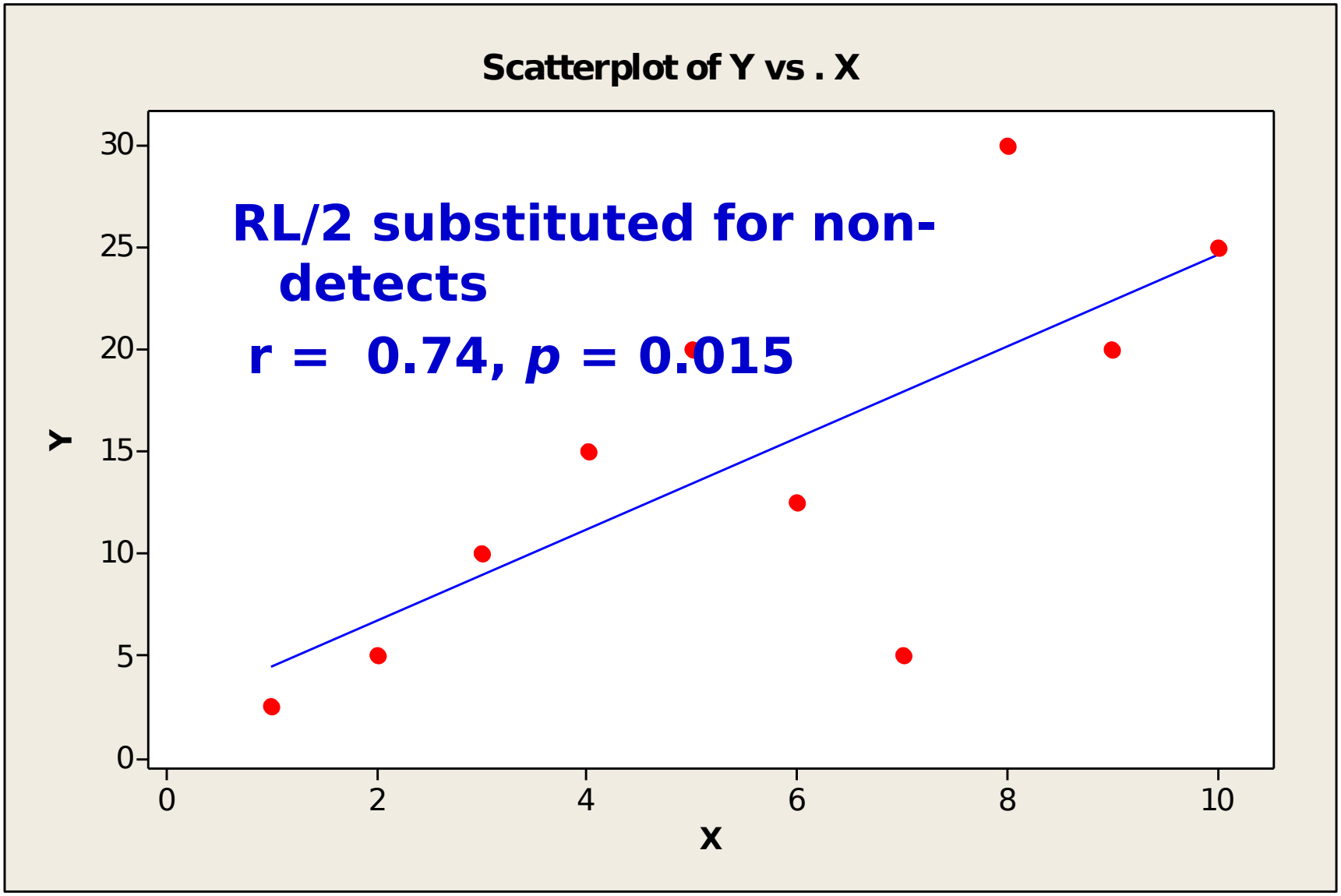
If there is reason to believe that the chemical is present in a sample at a concentration below the SQL [sample quantitation limit]*, use one-half of the SQL as a proxy concentration.*

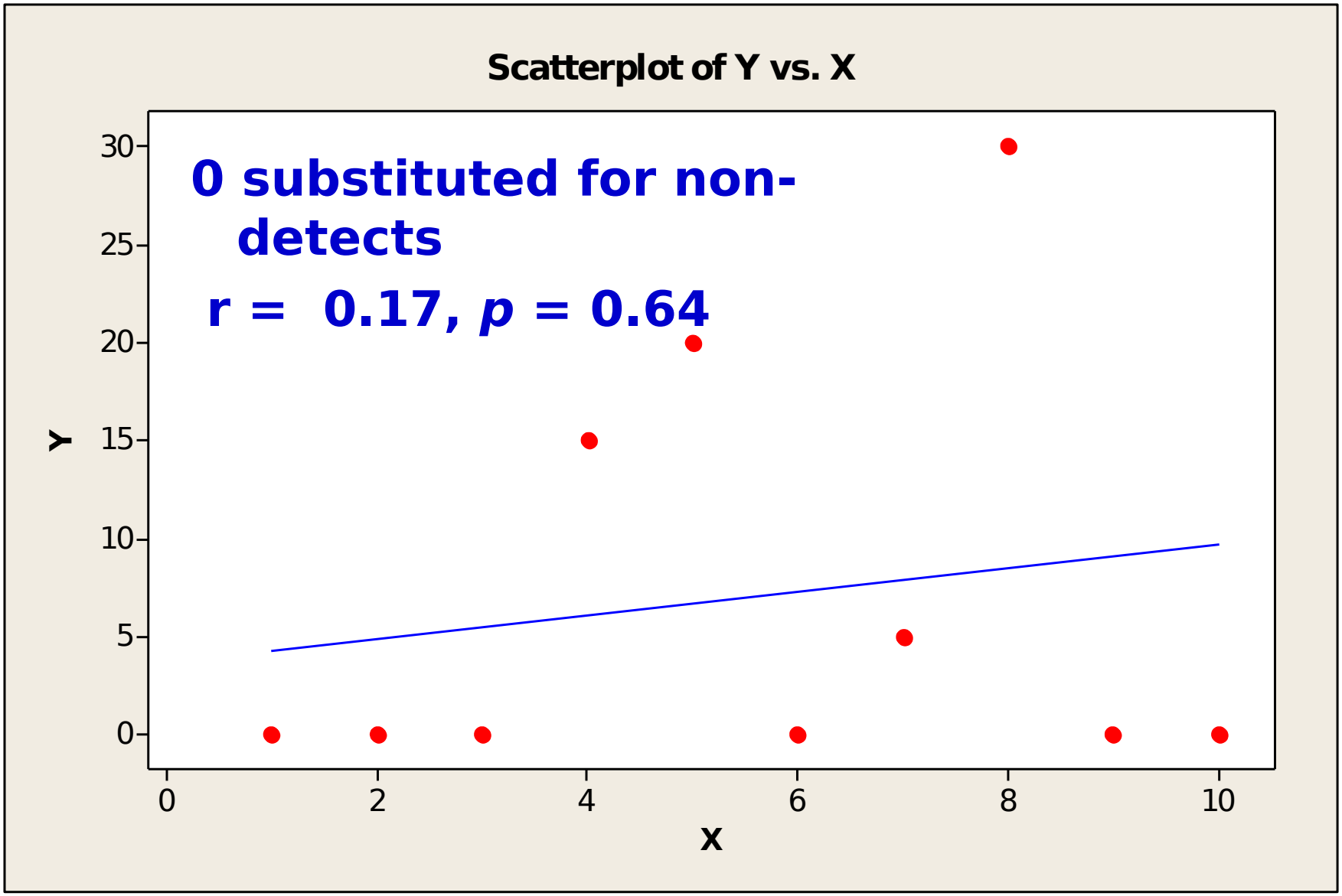
Pearson's r & Non-detects

- To calculate r, typically some multiple of the RL is substituted for non-detects.

X	Y	Flag	
1	5	U	(non-detect)
2	10	U	
3	20	U	
4	15		
5	20		
6	25	U	
7	5		
8	30		
9	40	U	
10	50	U	

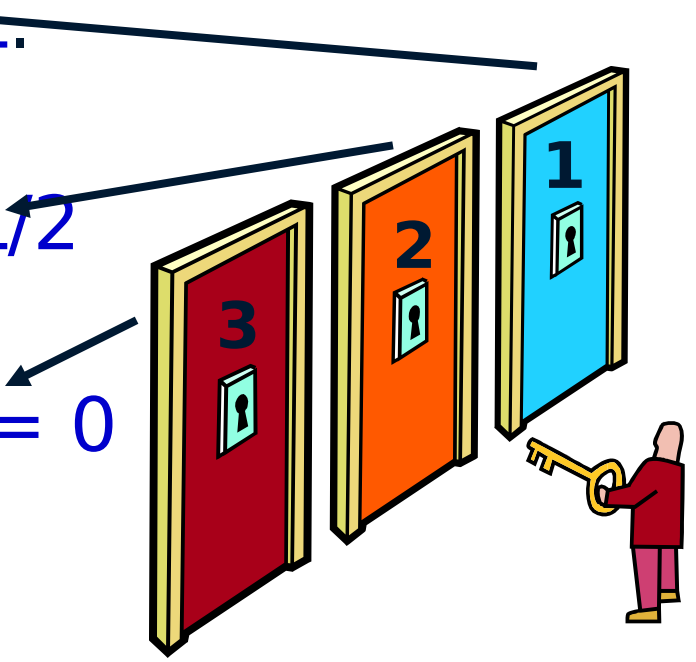

Scatterplot of Y vs. X
RL substituted for non-detects
r = 0.80, p = 0.006
(moderate correlation)
Regression line
Y
X
0
10
20
30
40
50
0
2
4
6
8
10


Scatterplot of Y vs . X
RL/2 substituted for non-detects
r = 0.74, p = 0.015
Y
X
0
5
10
15
20
25
30
0
2
4
6
8
10


Scatterplot of Y vs. X
0 substituted for non-detects
r = 0.17, p = 0.64
Y
X
0
5
10
15
20
25
30
0
2
4
6
8
10

Which result is correct?

1. r = 0.80, p = 0.006, RL
2. r = 0.74, p = 0.015, RL/2
3. r = 0.17, p = 0.64, RL = 0



There is no prize behind any of these doors !

Handling Non-detects

- **Do not use SM, as it distorts data sets and may result in erroneous conclusions.** Results depend on limits substituted for NDs.

- Avoid use of SM for parametric tests especially:
  - when a significant portion of the data is censored (e.g., > 10%);
  - RL is large (e.g., near decision limit or maximum);
  - there are multiple RLs with a wide range of values.

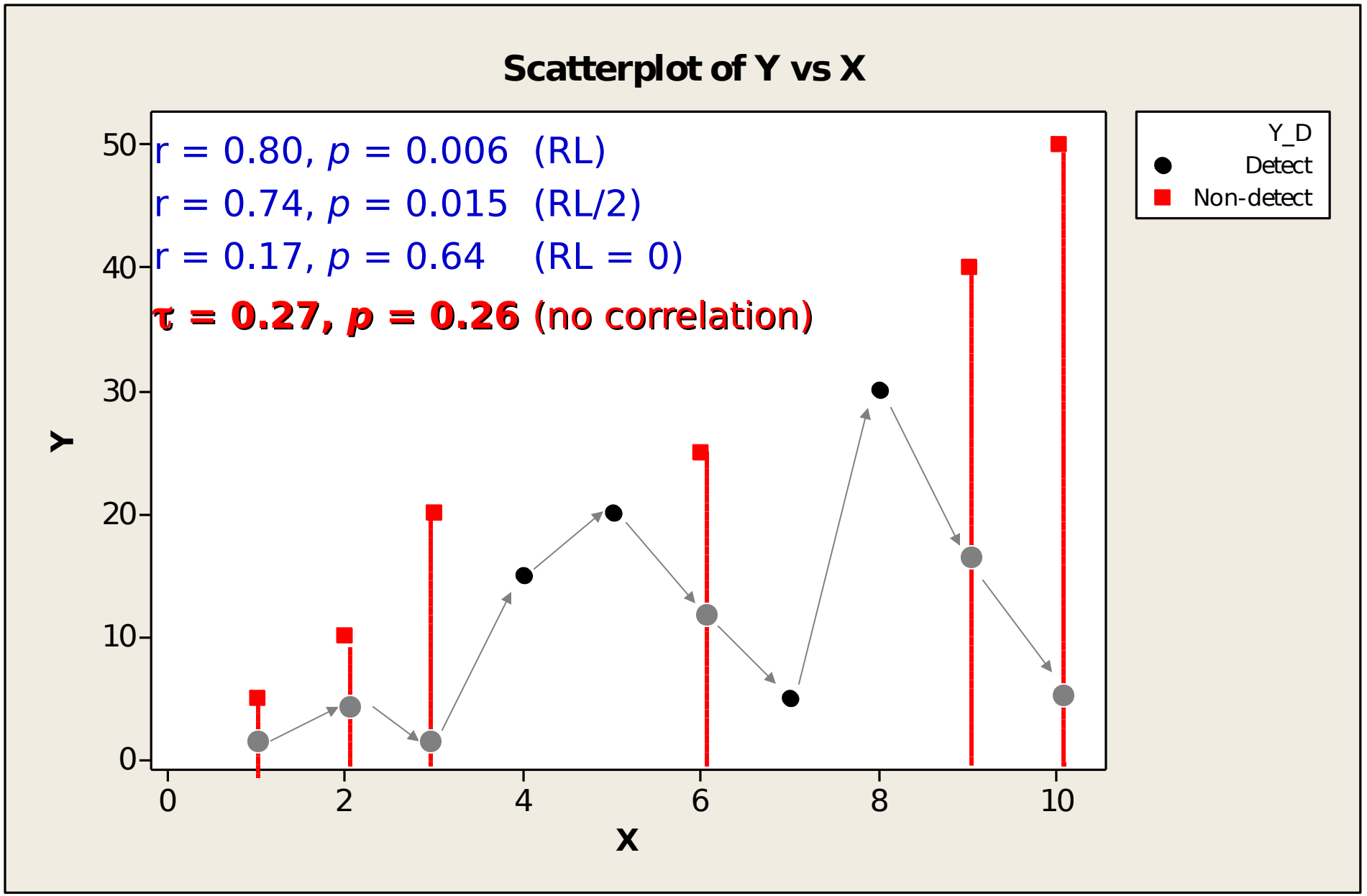
Sample data set for Pearson's r calculation

- 60% of data is censored.
- RLs are large (e.g., two exceed max detection).
- There are multiple (six different) RLs.

X	Y	Flag
1	5	U (non-detect)
2	10	U
3	20	U
4	15	
5	20	
6	25	U
7	5	
8	30	
9	40	U
10	50	U

Handling Non-detects

- Use **non-parametric** statistical methods. They are more “robust” to NDs; the results are less sensitive to RLs and number of NDs.
- Use Kendall’s τ rather than Pearson’s r to evaluate correlation when there are non-detects.


Scatterplot of Y vs X
r = 0.80, p = 0.006 (RL)
r = 0.74, p = 0.015 (RL/2)
r = 0.17, p = 0.64 (RL = 0)
τ = 0.27, p = 0.26 (no correlation)
Y_D
Detect
Non-detect
Y
X
0
10
20
30
40
50
0
2
4
6
8
10

Why is RL used for NDs for non-parametric but not parametric tests?

- RL is *not used as a numerical value* (e.g., but often as an inequality) for non-parametric methods.

- Example: Mean (for parametric tests) versus the median (for non-parametric tests).

  Data: <10, 20, 30

  Median: Half values fall above and half below.

  ND = RL: 10, 20, 30: **Mean = 20**, **Median = 20**

  ND = RL/2: 5, 20, 30: **Mean = 18.3**, **Median = 20**

Non-parametric Methods & NDs

- Caution: Non-parametric methods are more robust to NDs but results can be affected when large portion (e.g., > 50%) of data is censored.

- Example: Data: <10, < 20, 30. (67% censored)

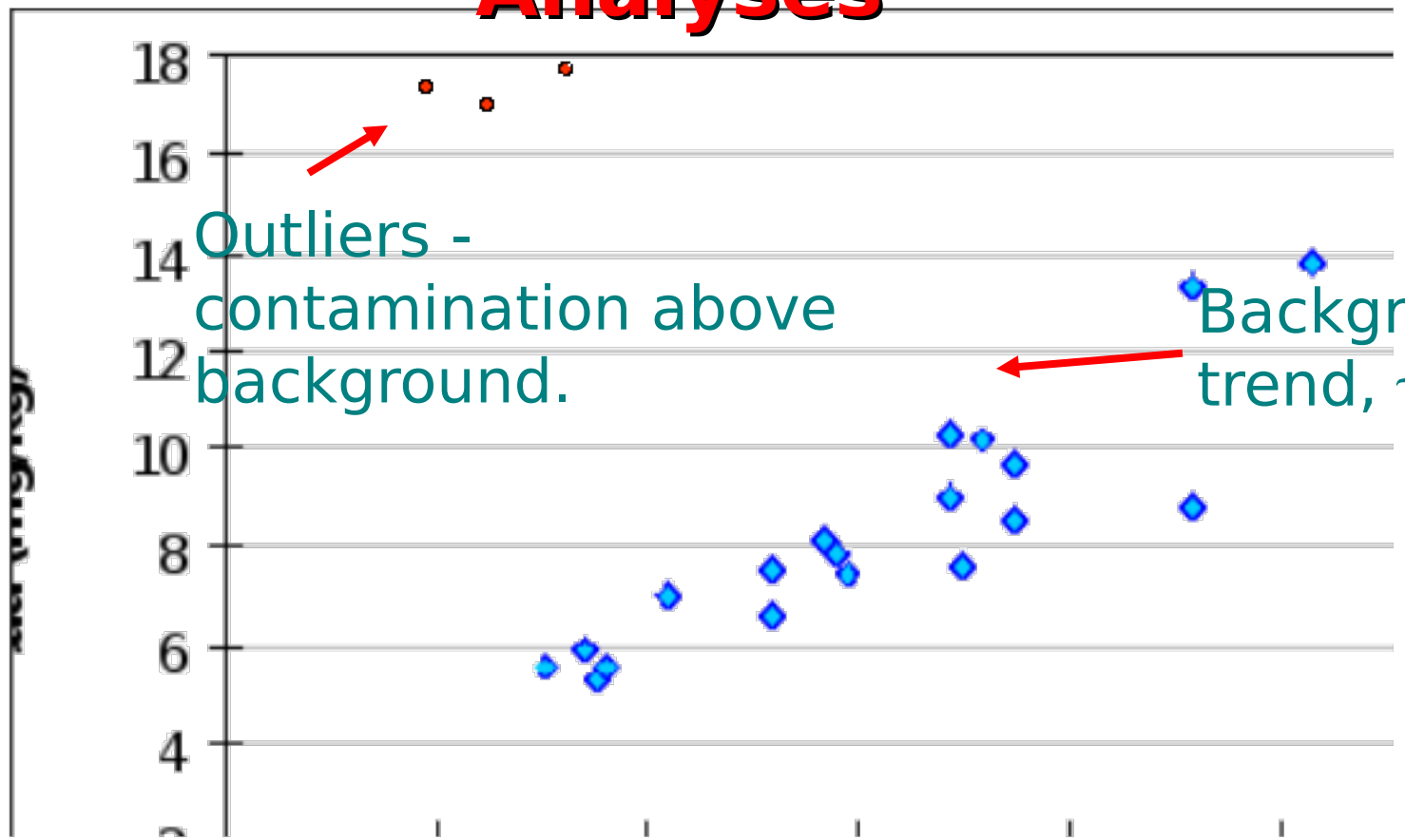
  Median is unknown, value < 20.

- **Always try to obtain numerical results from laboratories, even when measu values are less than the RL or zero !**

Statistical software that use non-parametric methods

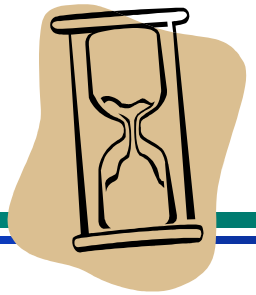
- Some statistical software packages that use non-parametric methods treat the RLs for non-detects as numerical values rather than as inequalities. **Do NOT use this software**.
  - If the software does not prompt you to distinguish between detects and non-detects when entering results (e.g., by asking you to code non-detects with a “0” and detects with a “1”), it is probably treating the RLs as numerical values.

Application for τ: Geochemical Association Analyses *



* EM 1110-1-4014, Appendix S (Shaw Environmental, Albuquerque NM)

Temporal Trend



- **Correlation** between some variable (usually concentration) and **time**. A trend exists if the **correlation coefficient** is significantly different (less or greater) than zero.

- Evaluated qualitatively using time series plots and quantitatively using hypotheses tests for the correlation coefficient.

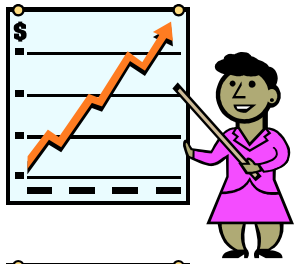
(Continued)

- Temporal **trend** exists if H_0: $\gamma = 0$ can be rejected with confidence (e.g., 95%).

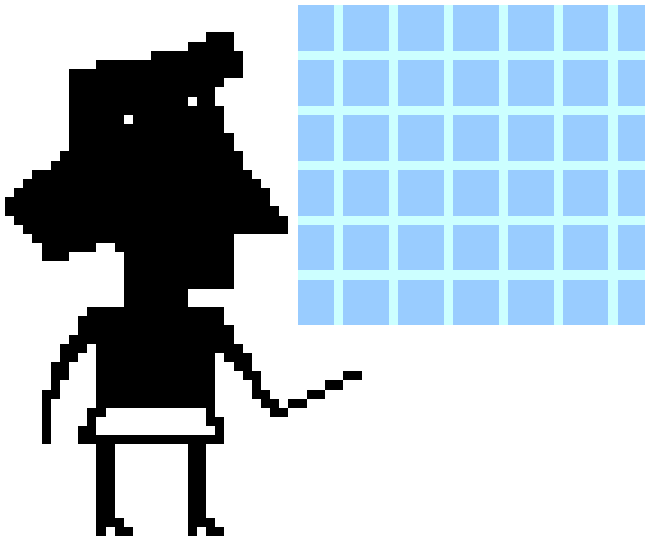
  $(t_1, y_1), (t_2, y_2)....(t_n, y_n) \rightarrow \gamma_s \rightarrow$ Reject H_0: $\gamma = 0$

  $\gamma_s > 0$ Upward trend

  $\gamma_s < 0$ Downward trend



Part 5.2
Simple Trends & Kendall's Tau



Example: Calculation of τ for Temporal Trends

Time (T) (month-year)	**TCE Concentration (Y)** (μg/L)
01-2001	335
02-2001	419
03-2001	366
04-2001	350
05-2001	391
06-2001	416
07-2001	431
08-2001	419

Step 1: List values (TCE concentrations) in order collected over time: y_1, y_2...

$n = 8$ pairs (t_i, y_i), i = 1, 2, ..., 8

Step 2

For n values y_i calculate the $[n(n - 1)/2]$ possible differences $y_j - y_i$ where j > i:

$y_2 - y_1, y_3 - y_1, \ldots, y_n - y_1, y_3 - y_2, y_4 - y_2 \ldots y_n - y_{n-1}$

How many $y_j - y_i$ pairs for $n = 3$?

$n(n - 1)/2 = 3(2)/2 = 3$

$y_2 - y_1, y_3 - y_1, y_3 - y_2$

$n = 10 \rightarrow 10(9)/2 = 45$

$n = 20 \rightarrow 19(20)/2 = 190$

Step 3

Define:

$\text{sign}(y_j - y_i) = 1$ if $y_j - y_i > 0$ (Positive pair)

$= -1$ if $y_j - y_i < 0$ (Negative pair)

$= 0$ if $y_j - y_i = 0$ (Tie

Steps 4 & 5

Step 4: Sum all sign($y_j - y_i$) values:

$S = \Sigma_i \Sigma_j \text{ sign}(y_j - y_i)$, $j = i + 1,\ldots n$ & $i = 1, \ldots n - 1$

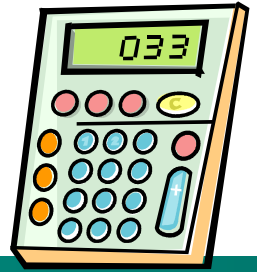
Step 5: Calculate: $\tau = S / [n (n - 1)/2]$

Note:

τ = {No. positive pairs – No. negative pairs} /Total

TCE	**419** (y_2)	**366** (y_3)	**350** (y_4)	**391** (y_5)	**416** (y_6)	**431** (y_7)	**419** (y_8)	**Sum**
335 (y_1)	1 419 - 335 > 0	1 366 - 335 > 0	1	1	1	1	1	7
419 (y_2)		-1	-1	-1	-1	1	0	-3
366 (y_3)			-1	1	1	1	1	3
350 (y_4)				1	1	1	1	4
391 (y_5)					1	1	1	3
416 (y_6)						1	1	2
431 (y_7)							-1	-1
419 (y_8)				191				**S = 15**

Sample Calculation of τ



$\tau = S/[n\,(n-1)/2]$, $n = 8$, $S = 15$

$\tau = 15/[8(8-1)/2] = 0.54$ → **Possible upward trend**

Is the trend "real"? Need Hypothesis test:

$H_0: \tau = 0$, $H_1: \tau \neq 0$ (test for non-directional trend)

$H_1: \tau \leq 0$, $H_1: \tau > 0$ (test for upward trend only)

Hypothesis Tests for τ, $n > 10$

- S approximately normal for large *n:*

  $Z \approx (S - \mu_S)/\sigma_S$

  $\mu_S = 0$ when there is no trend

  $\sigma_S^2 = n(n - 1)(2n + 5)/18$ (variance)

  $Z = (S - 1)/\sigma_S$ if $S > 0$ (test statistic)

  $= (S + 1)/\sigma_S$ if $S < 0$

  $= 0$ if $S = 0$

Hypothesis Tests for τ

- 1) $H_0: \tau \leq 0$, $H_1: \tau > 0$: Upward trend if $Z > Z_{1-\alpha}$

  2) $H_0: \tau \geq 0$, $H_1: \tau < 0$: Downward trend if $Z < -Z_{1-\alpha}$

  3) $H_0: \tau = 0$, $H_1: \tau \neq 0$: Trend if $|Z| > Z_{1-\alpha/2}$

- Note: Test for *directional* or *one-sided* trend (Case 1 & 2 above) at $(1 - \alpha_{1\text{-sided}})100\%$ CL (e.g., 95% CL) is equivalent to test for *non-directional* trend (Case 3) at $(1 - 2\ \alpha_{1\text{-sided}})100\%$ CL (e.g., 90% CL).

Example*

(*Note: Large *n* test used even though *n* < 10.)

$n = 8$, S =15, $\alpha = 0.05$ (95% CL), $Z_{1-\alpha} = 1.64$

$\sigma_S = [n\,(n - 1)(2n + 5)/18]^{1/2} = 8.08$

$Z = (S - 1)/\sigma_S = 14/8.08 = 1.73$

$H_0: \tau \leq 0$, $H_1: \tau > 0$, $(1 - \alpha_{1\text{-sided}})$

$Z = 1.73 > Z_{0.95} = 1.64 \rightarrow$ Upward trend 95% CL

$H_0: \tau = 0$, $H_1: \tau \neq 0$, $Z_{1-\alpha/2= 0.975} = 1.96$

$|Z| = 1.73 < 1.96 \rightarrow$ No trend at 95% CL

$|Z| = 1.73 > 1.64 \rightarrow$ Trend at 90% CL $(1 - 2 \times \alpha_{1\text{-sided}})$

Software for Hypothesis Tests

- VSP uses critical value approach:

  $H_0: \tau = 0$, $H_1: \tau \neq 0$ →

  MK (Mann-Kendall) *test statistic* (Z) = 1.74

  MK Critical Value ($Z_{1-\alpha/2\ =0.95}$) = 1.64 …

  Upward or Downward Monotonic Trend Detected with 10% Alpha (90% confidence)

- MiniTab uses p-value approach:

  $H_0: \tau = 0$, $H_1: \tau \neq 0$ → p-value = 0.081

  Trend at 90% ($p < \alpha = 0.1$) but not 95% CL ($p > \alpha = 0.05$).

Hypothesis Tests for τ, $n \leq 10$

- Use table (e.g., EM 110-1-4014, Table 10, probabilities for one-sided Mann-Kendall test):

  $H_0: \tau \leq 0$, $H_1: \tau > 0$ → $p \approx 0.0425$ (from interpolation for S = 15) < 0.05 → Upward trend at 95% confidence.

	p	
S	***n* = 8**	***n* = 9**
12	0.089	0.130
14	**0.054**	0.090
16	**0.031**	0.060
18	0.016	0.038

Note: p-value for two-tailed test = 2 $p \approx$ 0.08

(No trend at 95% CL but trend at 90% CL.)

Tied Values and τ

- Ties decrease τ (S approaches 0). Non-detects appear as tied values.

Time:	01/07	02/07	03/07	04/07	05/07…
Conc.	20	<10	<10	<3	7

For example, when calculating S:

20 → <10 or <3	Decrease; assign - 1
<10 → <10, <3, or 7	Tie; assign 0

Kendall's τ_b

- Kendall's τ adjusted for tied values.

$$\tau_b = \frac{S}{\{[n\,(n-1)/2] - \#\,\text{ties}_X\}^{1/2}\,\{[n\,(n-1)/2] - \#\,\text{ties}_Y\}^{1/2}}$$

Typically, X = Time, Y = Conc. and # $\text{ties}_X = 0$.

Note: If there are no ties $\tau_b = \tau$ (sometimes denoted as τ_a); otherwise $\tau_b > \tau$

Kendall's τ_b and τ

- The test statistic for τ and τ_b (for $n > 10$),

$$Z = (S \pm 1)/\sigma_S$$

is adjusted for ties using an equation that adjusts (decreases) σ_S for ties. (Statistical software does this automatically.)

- Tie-adjusted σ_S:

$$\sigma^2_S = (1/18)n(n-1)(2n+5) - \Sigma_k\, h_k\,(h_k-1)(2h_k+5)$$

g = Number of tied groups

h_k = Number of tied values in k^{th} group, k = 1, 2,... g

Example:

	Time	t_1	t_2	...
Y	23, 23,	24, 24, 24,	29, 29, 29,	6

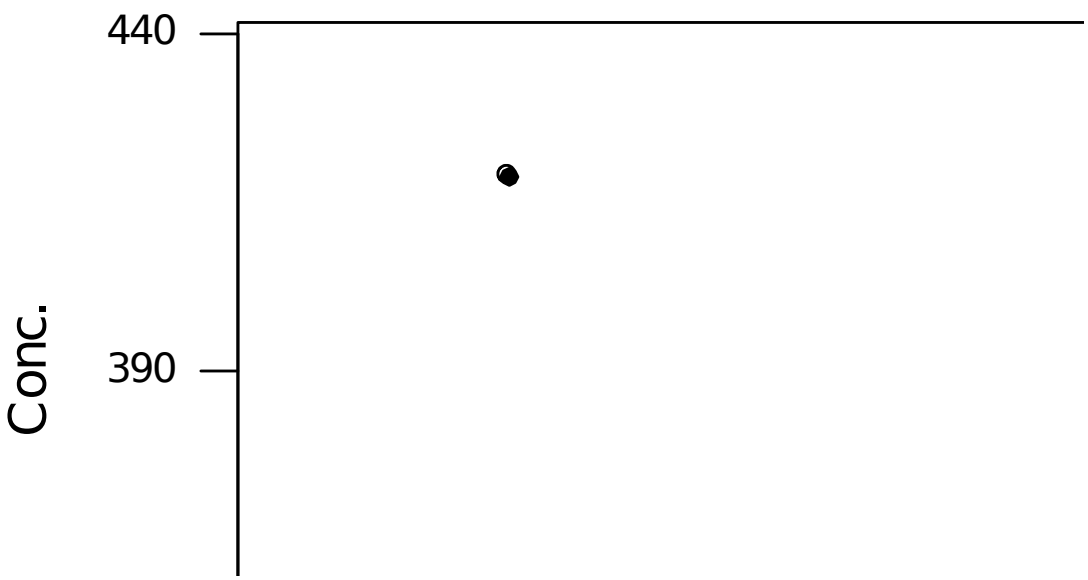
g = 3 $h_1 = 2$ $h_2 = 3$ $h_3 = 3$

Data on Slide 187

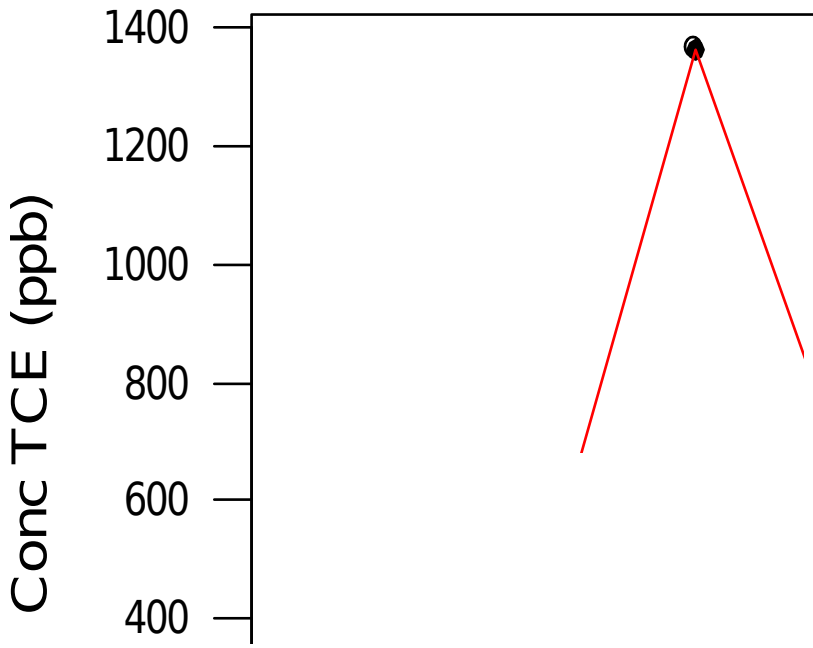
$\tau = 0.536$, $\tau_b = 0.546$ (one tie)

$p = 0.081$

(two-tailed test)



Times Series (Scatter) Plot

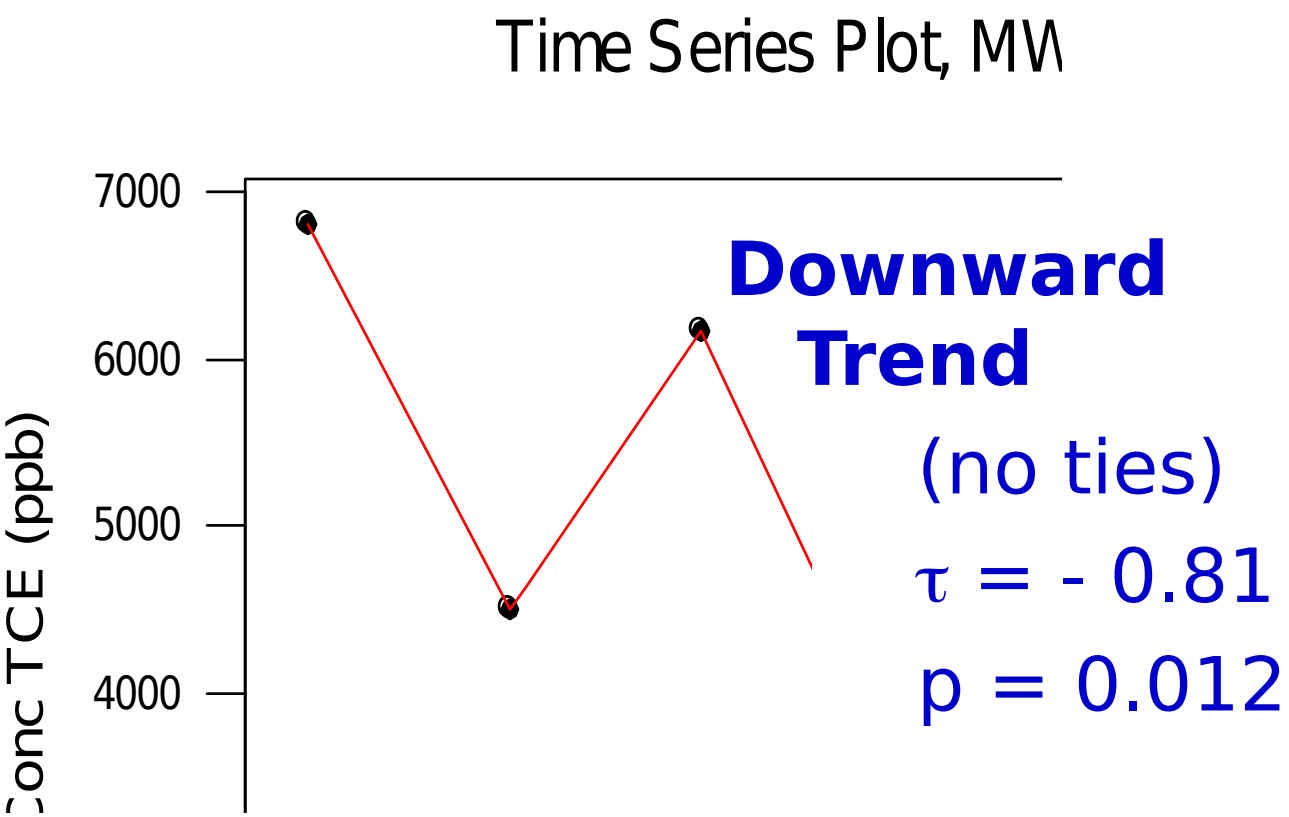


No Trend

(no ties)

$\tau = 0.24$,

$p = 0.55$

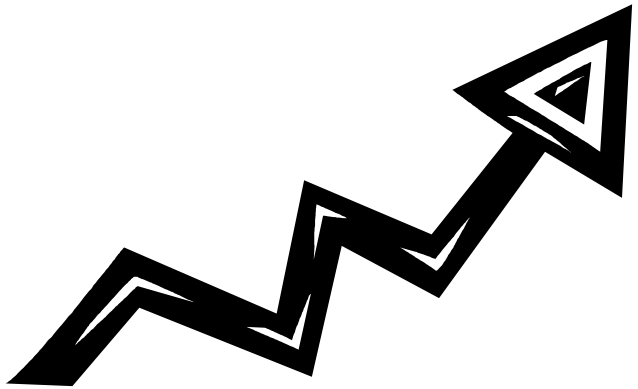

Time Series Plot, MW
7000
6000
5000
4000
Conc TCE (ppb)
Downward Trend
(no ties)
τ = - 0.81
p = 0.012
2004

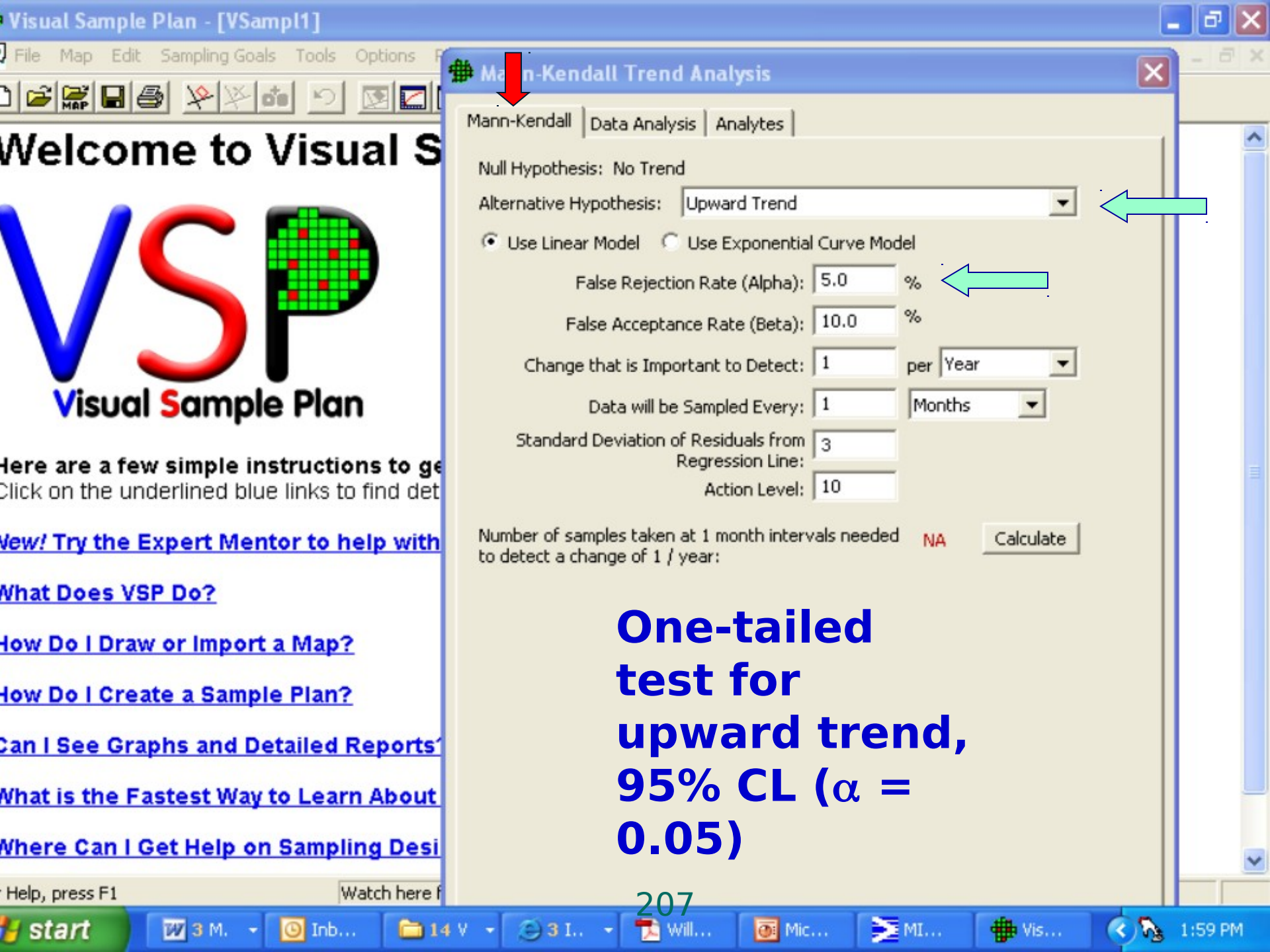
Part 5.3
Simple Trends and Visual Sampling Plan (VSP) Software

Evaluating Simple Trends

- **Menu**

  Sampling Goals → Detect a Trend → Data not required to be normally distributed → No Seasonality

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VSP
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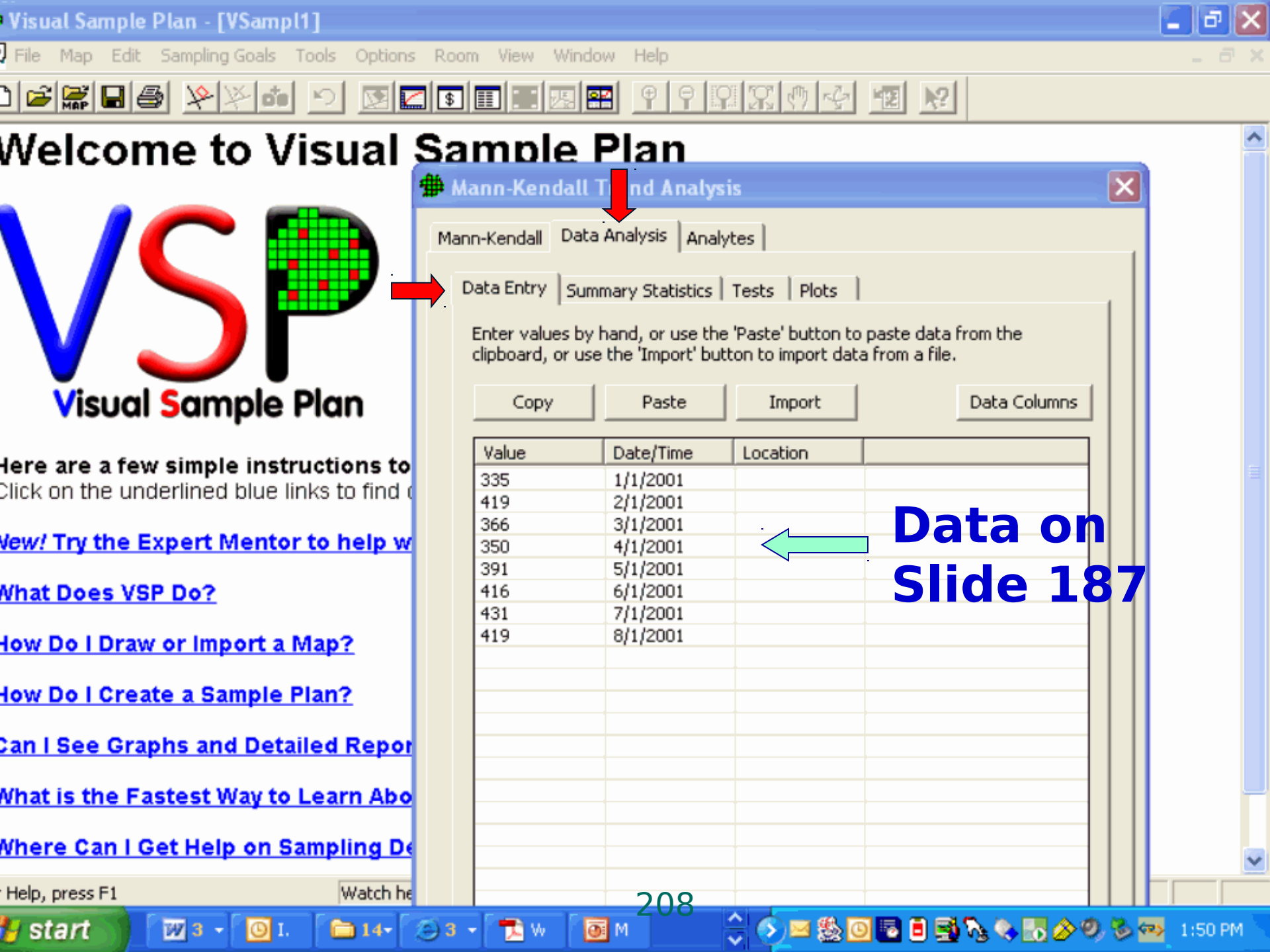
New! Try the Expert Mentor to help with
What Does VSP Do?
How Do I Draw or Import a Map?
How Do I Create a Sample Plan?
Can I See Graphs and Detailed Reports
What is the Fastest Way to Learn About
Where Can I Get Help on Sampling Desi
Help, press F1
Watch here f
Mann-Kendall Trend Analysis
Mann-Kendall
Data Analysis
Analytes
Null Hypothesis: No Trend
Alternative Hypothesis: Upward Trend
Use Linear Model
Use Exponential Curve Model
False Rejection Rate (Alpha): 5.0 %
False Acceptance Rate (Beta): 10.0 %
Change that is Important to Detect: 1 per Year
Data will be Sampled Every: 1 Months
Standard Deviation of Residuals from Regression Line: 3
Action Level: 10
Number of samples taken at 1 month intervals needed to detect a change of 1 / year:
NA
Calculate
One-tailed test for upward trend, 95% CL (α = 0.05)
start
3 M.
Inb...
14 V
3 I..
Will...
Mic...
MI...
Vis...
1:59 PM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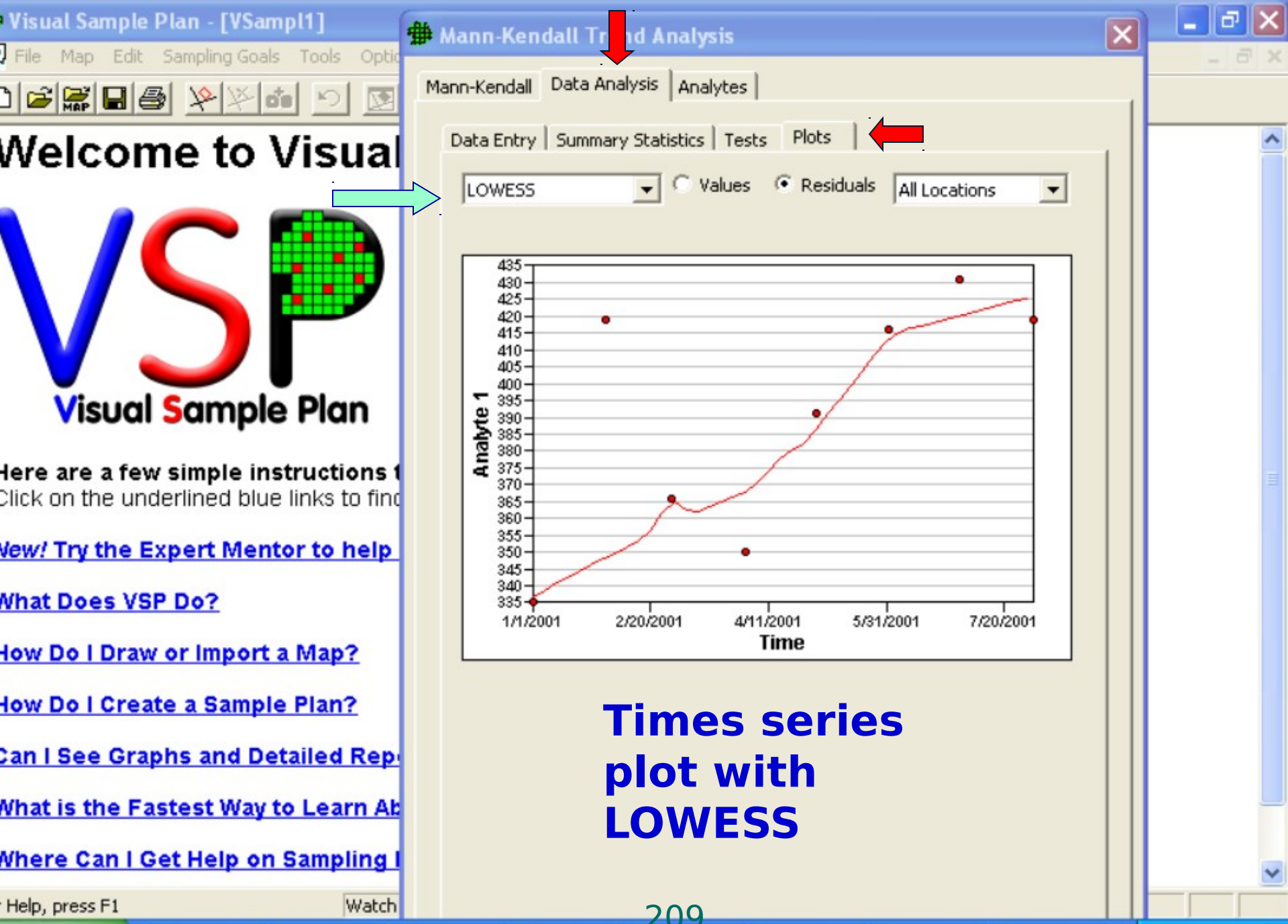
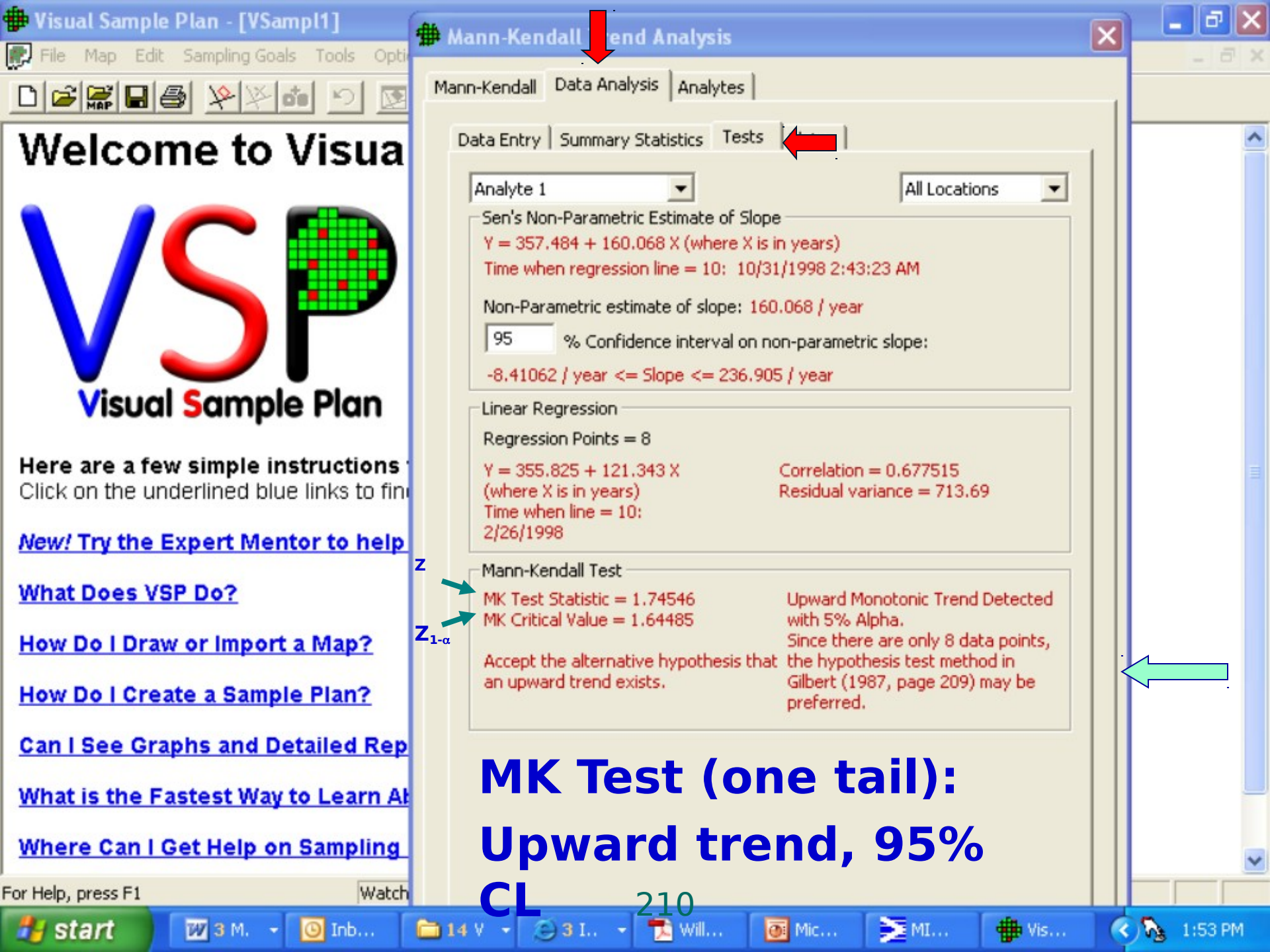
How Do I Create a Sample Plan?
Can I See Graphs and Detailed Repor
What is the Fastest Way to Learn Abo
Where Can I Get Help on Sampling De
Help, press F1
Watch he
Mann-Kendall Trend Analysis
Mann-Kendall
Data Analysis
Analytes
Data Entry
Summary Statistics
Tests
Plots
Enter values by hand, or use the 'Paste' button to paste data from the clipboard, or use the 'Import' button to import data from a file.
Copy
Paste
Import
Data Columns
Value
Date/Time
Location
335 1/1/2001
419 2/1/2001
366 3/1/2001
350 4/1/2001
391 5/1/2001
416 6/1/2001
431 7/1/2001
419 8/1/2001
Data on Slide 187
start
1:50 PM



Times series plot with LOWESS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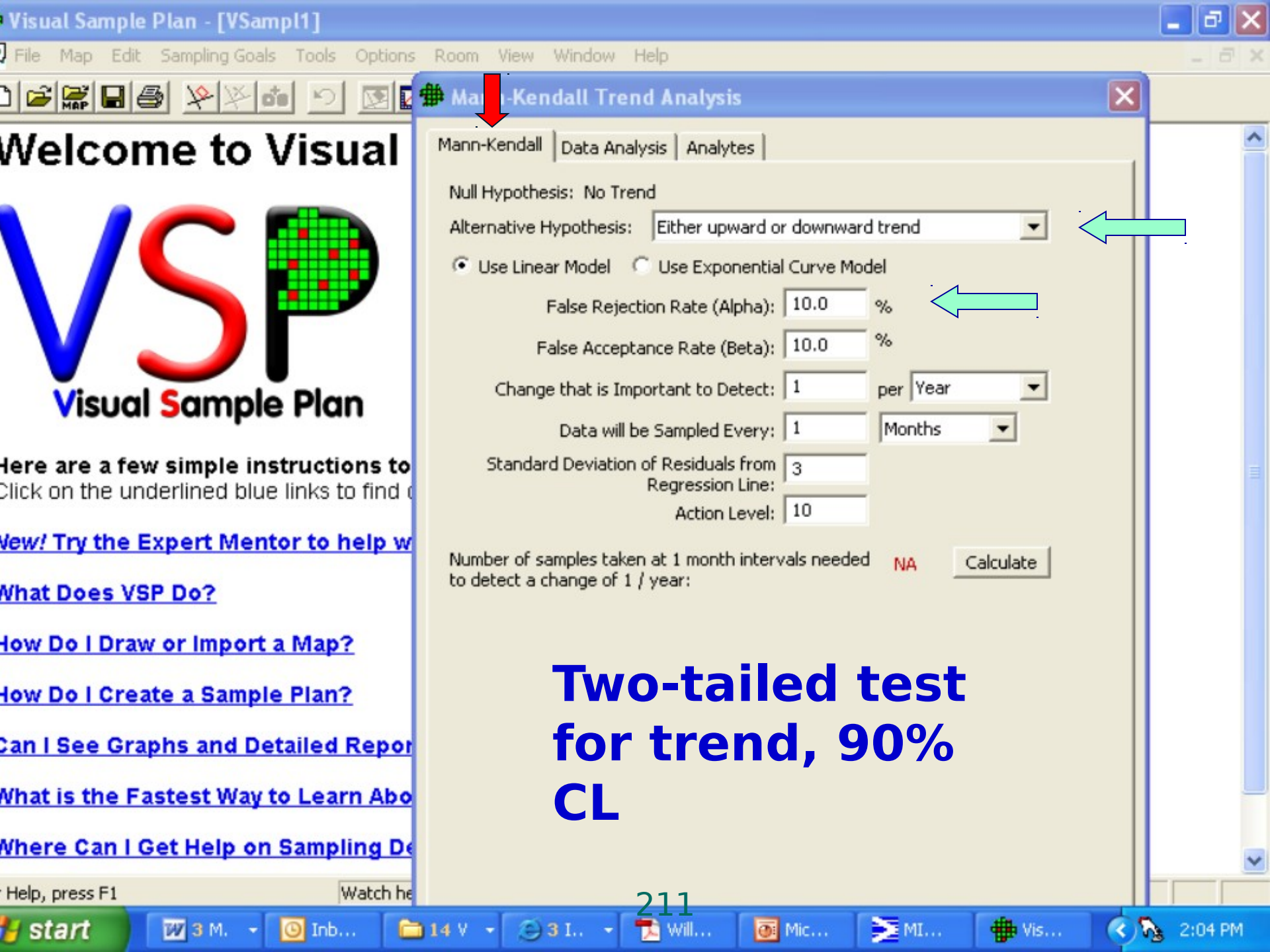
For Help, press F1
Mann-Kendall Trend Analysis
Mann-Kendall
Data Analysis
Analytes
Data Entry
Summary Statistics
Tests
Analyte 1
All Locations
Sen's Non-Parametric Estimate of Slope
Y = 357.484 + 160.068 X (where X is in years)
Time when regression line = 10: 10/31/1998 2:43:23 AM
Non-Parametric estimate of slope: 160.068 / year
95
% Confidence interval on non-parametric slope:
-8.41062 / year <= Slope <= 236.905 / year
Linear Regression
Regression Points = 8
Y = 355.825 + 121.343 X
(where X is in years)
Time when line = 10:
2/26/1998
Correlation = 0.677515
Residual variance = 713.69
Mann-Kendall Test
Z
MK Test Statistic = 1.74546
MK Critical Value = 1.64485
Z1-α
Accept the alternative hypothesis that an upward trend exists.
Upward Monotonic Trend Detected with 5% Alpha.
Since there are only 8 data points, the hypothesis test method in Gilbert (1987, page 209) may be preferred.
MK Test (one tail):
Upward trend, 95% CL
start
1:53 PM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Calculate
Two-tailed test for trend, 90% CL
start
3 M.
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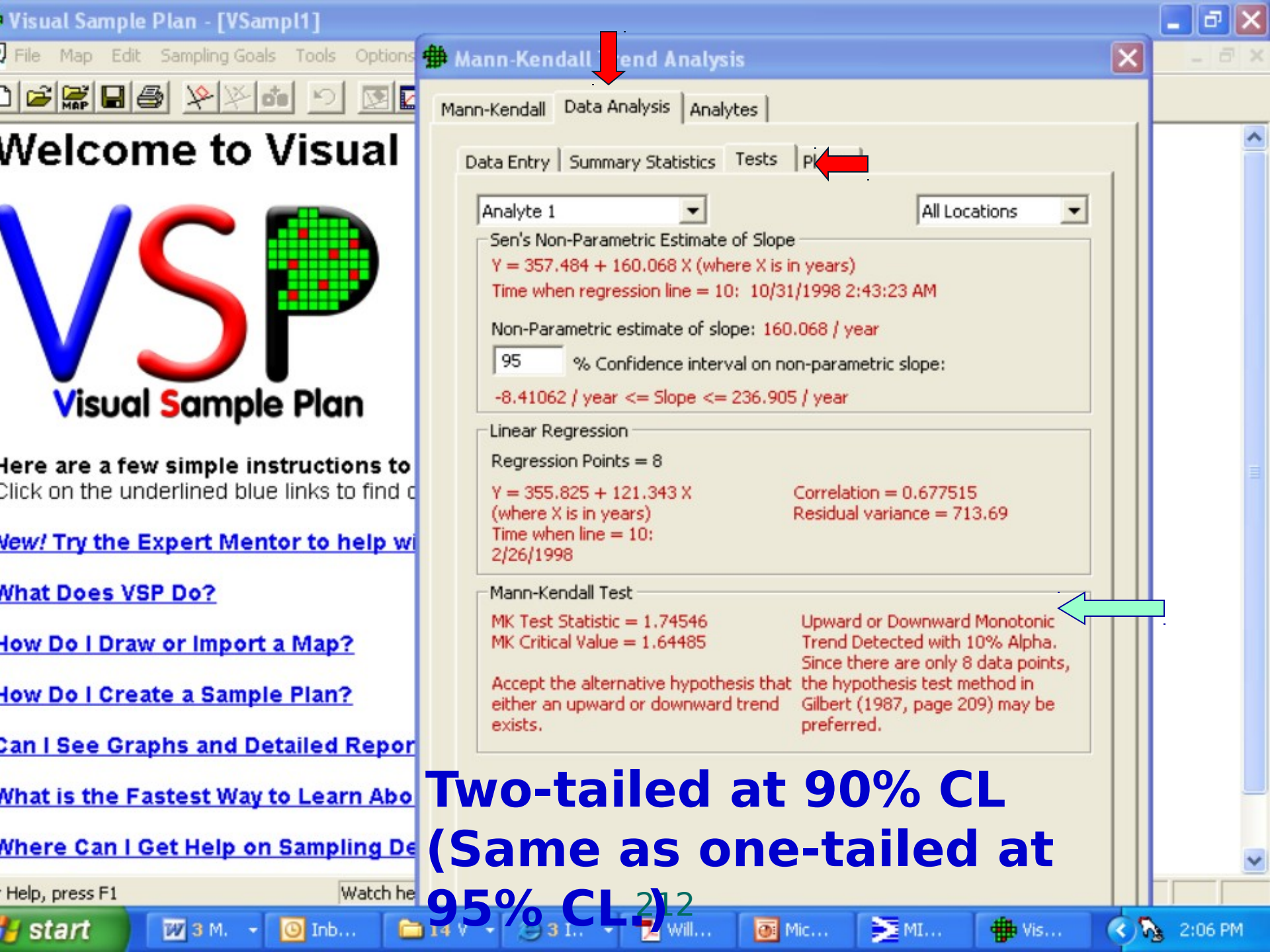
Vis...
2:04 PM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Mann-Kendall Trend Analysis
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All Locations
Sen's Non-Parametric Estimate of Slope
Y = 357.484 + 160.068 X (where X is in years)
Time when regression line = 10: 10/31/1998 2:43:23 AM
Non-Parametric estimate of slope: 160.068 / year
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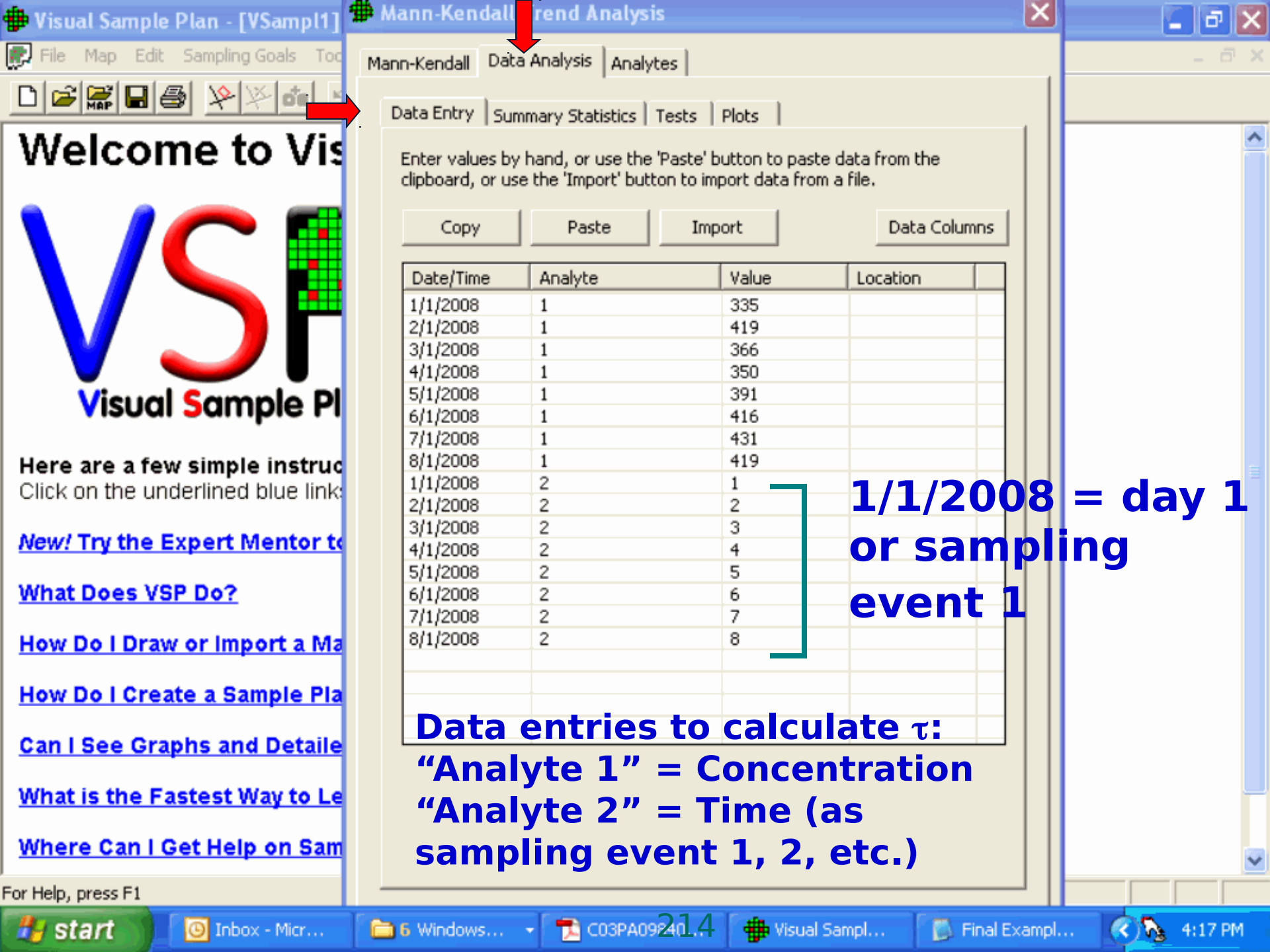
Correlation = 0.677515
Residual variance = 713.69
Mann-Kendall Test
MK Test Statistic = 1.74546
MK Critical Value = 1.64485
Accept the alternative hypothesis that either an upward or downward trend exists.
Upward or Downward Monotonic Trend Detected with 10% Alpha. Since there are only 8 data points, the hypothesis test method in Gilbert (1987, page 209) may be preferred.
Two-tailed at 90% CL
(Same as one-tailed at
95% CL)
212
start
2:06 PM

Calculating Kendall's Tau

- VSP does not directly output τ for trend evaluations.
- VSP calculates correlation coefficients but not when one of the variables is time and dates are entered.
- Values of time variable need to be converted to sequential numerical values before calculating τ.
- **Menu**

  Tools → Correlate Analyte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Mann-Kendall
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Data Entry
Summary Statistics
Tests
Plots
Enter values by hand, or use the 'Paste' button to paste data from the clipboard, or use the 'Import' button to import data from a file.
Copy
Paste
Import
Data Columns
Date/Time | Analyte | Value | Location
1/1/2008 | 1 | 335
2/1/2008 | 1 | 419
3/1/2008 | 1 | 366
4/1/2008 | 1 | 350
5/1/2008 | 1 | 391
6/1/2008 | 1 | 416
7/1/2008 | 1 | 431
8/1/2008 | 1 | 419
1/1/2008 | 2 | 1
2/1/2008 | 2 | 2
3/1/2008 | 2 | 3
4/1/2008 | 2 | 4
5/1/2008 | 2 | 5
6/1/2008 | 2 | 6
7/1/2008 | 2 | 7
8/1/2008 | 2 | 8
1/1/2008 = day 1 or sampling event 1
Data entries to calculate τ:
“Analyte 1” = Concentration
“Analyte 2” = Time (as sampling event 1, 2, etc.)
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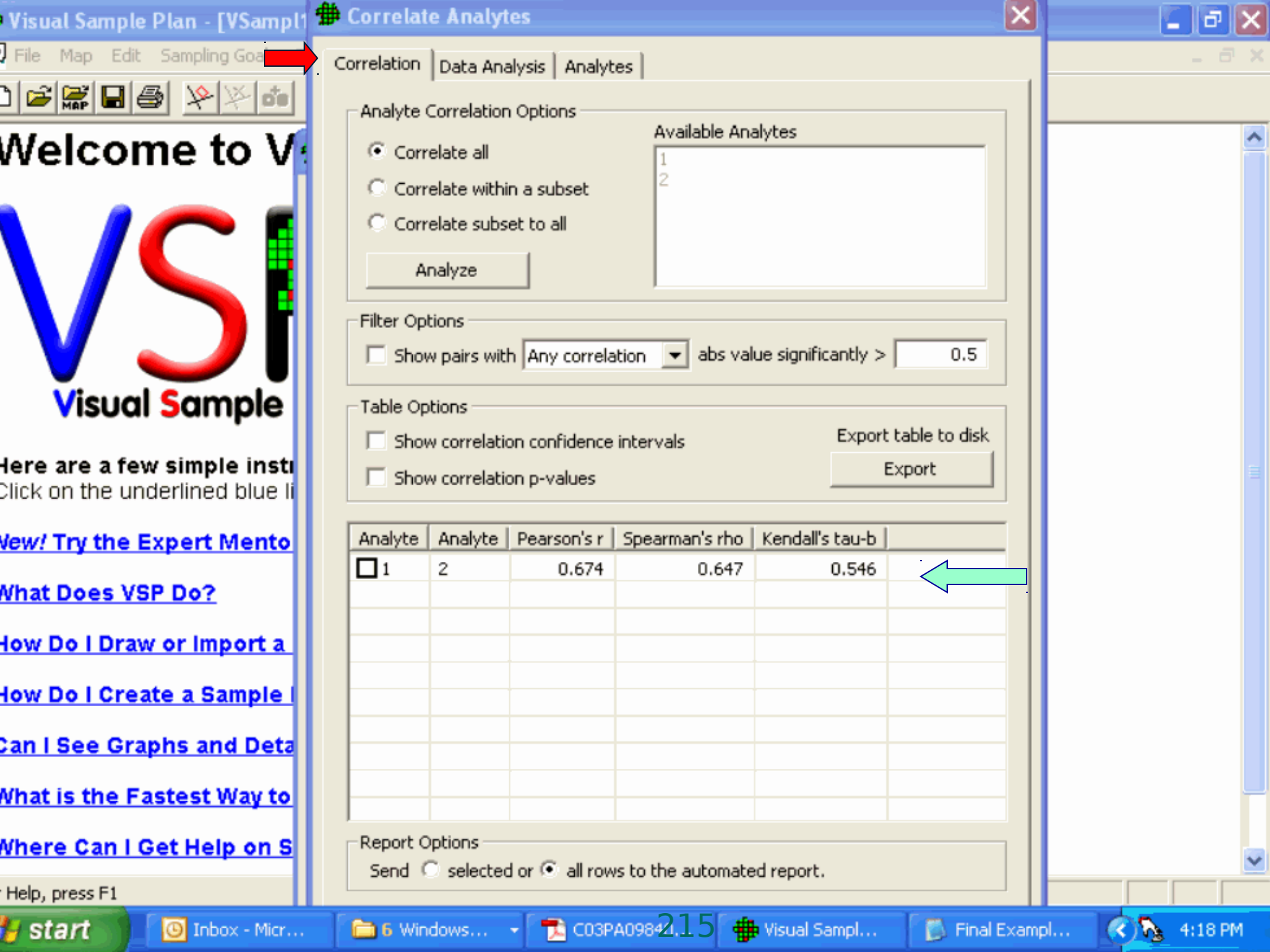
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Correlation
Data Analysis
Analytes
Analyte Correlation Options
Correlate all
Correlate within a subset
Correlate subset to all
Analyze
Available Analytes
1
2
Filter Options
Show pairs with
Any correlation
abs value significantly >
0.5
Table Options
Show correlation confidence intervals
Show correlation p-values
Export table to disk
Export
Analyte
Analyte
Pearson's r
Spearman's rho
Kendall's tau-b
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2
0.674
0.647
0.546
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selected or
all rows to the automated report.
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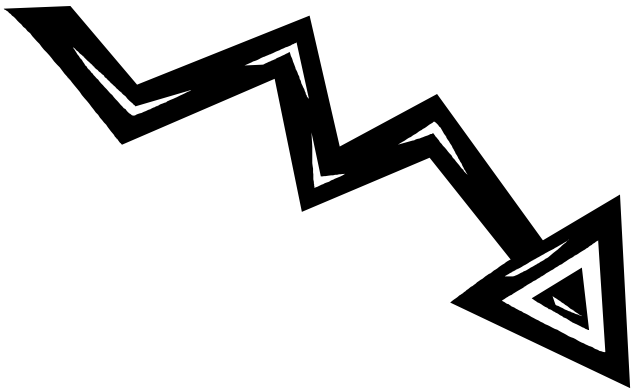
Part 5.4
Power Determinations for Simple Trends Using VSP

Determining the Number of Sampling Events to Detect Simple Trends

- Objective: Show that a downward trend exists in one or more groundwater monitoring wells (e.g., to show natural attenuation is occurring).

- Problem: How long must samples be collected to detect (demonstrate) a downward trend?



Example of Data Quality Objectives (DQOs) for Simple Trends

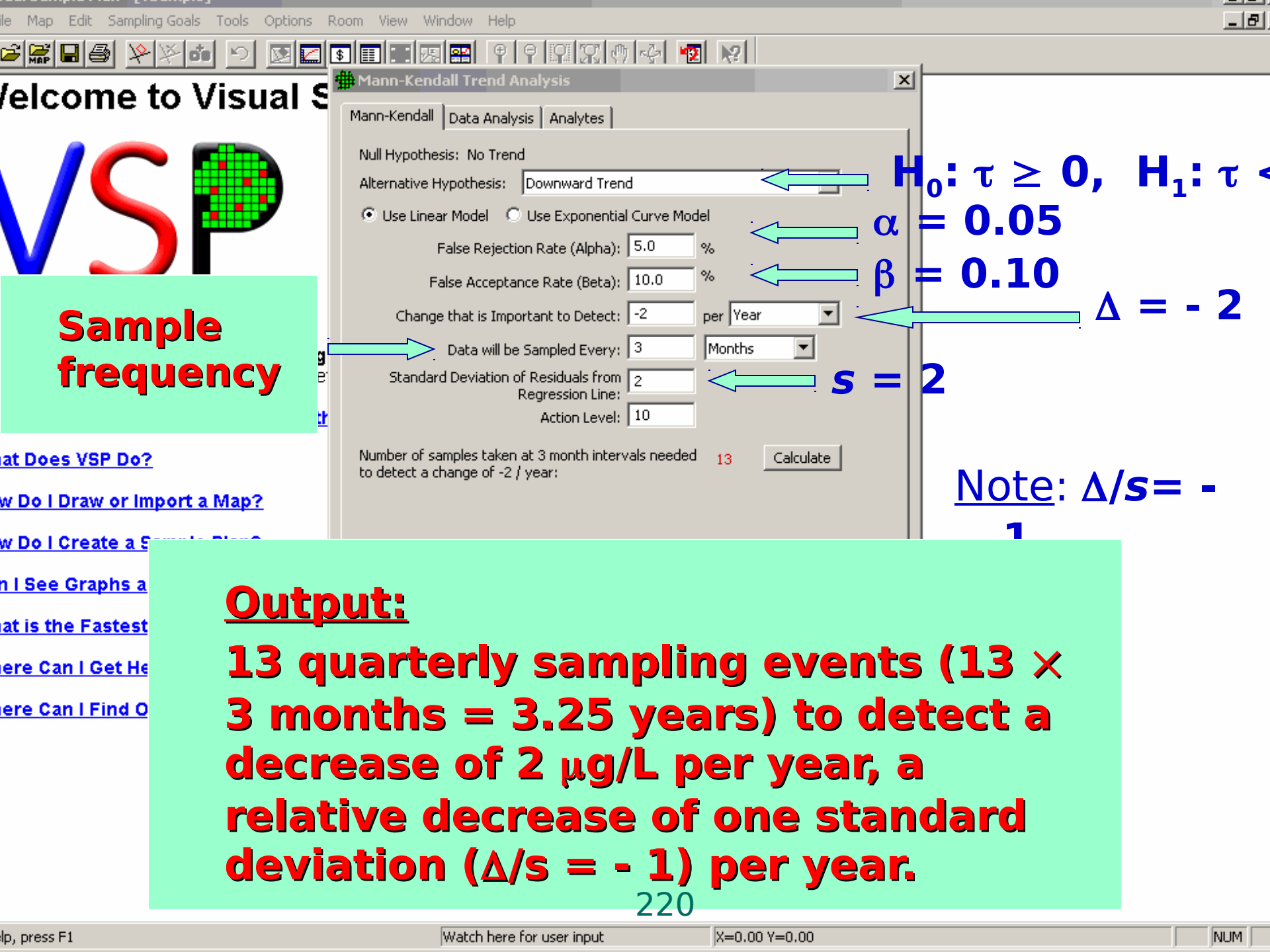
- Demonstrate trend with 95% confidence, α = 0.05.
- Background Information: Action Level = 10 μg/L,

  Mean conc. = 20 μg/L, s = 2 μg/L
- A decrease of 2 μg/L (1 standard deviation) per year (Δ/s = -1) is considered significant.
- Need to be able to detect this change with 90% confidence (power), β = 0.10.

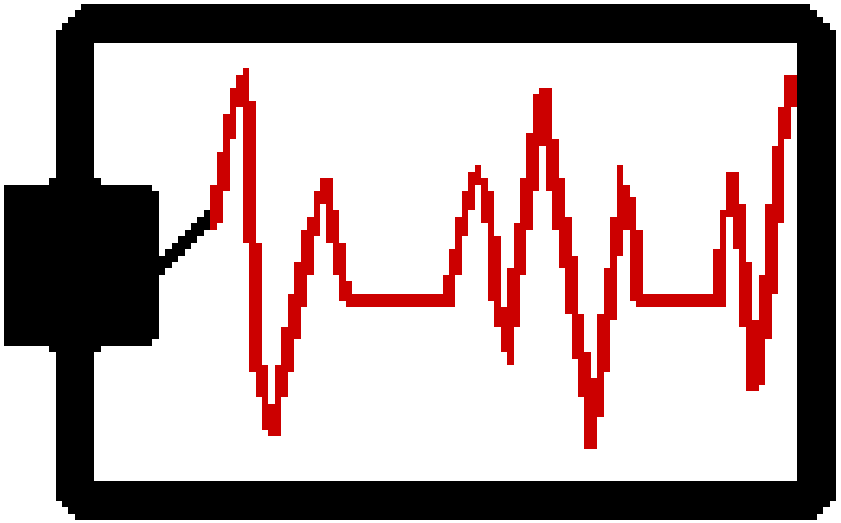
Detecting Simple Trends

- **Menu**

  Sampling Goals → Detect a Trend → Data not required to be normally distributed → No Seasonality

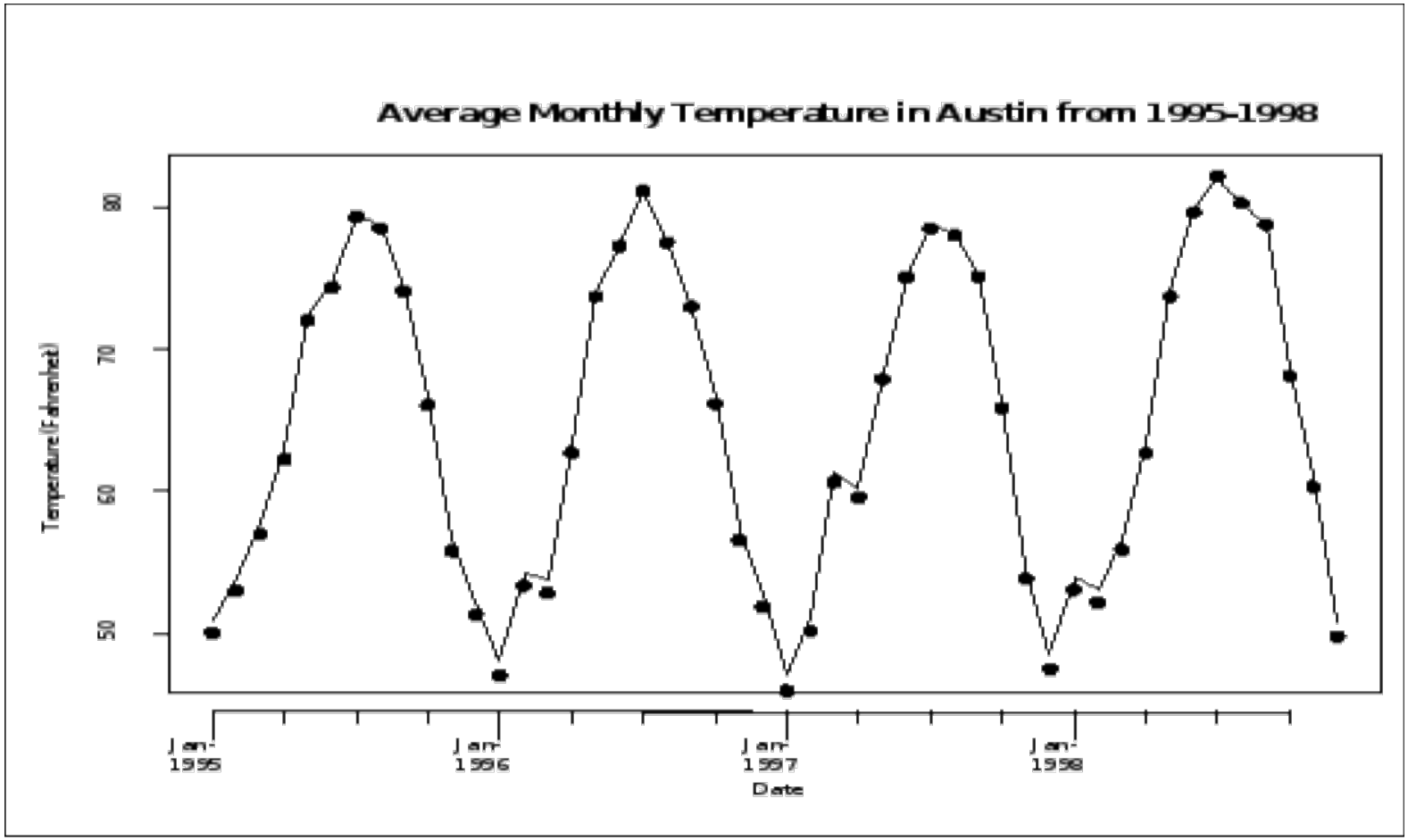

Map Edit Sampling Goals Tools Options Room View Window Help
Welcome to Visual S
VSP
Mann-Kendall Trend Analysis
Mann-Kendall
Data Analysis
Analytes
Null Hypothesis: No Trend
Alternative Hypothesis: Downward Trend
Use Linear Model
Use Exponential Curve Model
False Rejection Rate (Alpha): 5.0 %
False Acceptance Rate (Beta): 10.0 %
Change that is Important to Detect: -2 per Year
Data will be Sampled Every: 3 Months
Standard Deviation of Residuals from Regression Line: 2
Action Level: 10
Number of samples taken at 3 month intervals needed to detect a change of -2 / year: 13
Calculate
Sample frequency
$H_0: \tau \geq 0$, $H_1: \tau <$
$\alpha = 0.05$
$\beta = 0.10$
$\Delta = -2$
$s = 2$
Note: $\Delta/s = -1$
What Does VSP Do?
How Do I Draw or Import a Map?
How Do I Create a
Can I See Graphs a
What is the Fastest
Where Can I Get He
Where Can I Find O
Output:
13 quarterly sampling events (13 × 3 months = 3.25 years) to detect a decrease of 2 μg/L per year, a relative decrease of one standard deviation (Δ/s = - 1) per year.
Help, press F1
Watch here for user input
X=0.00 Y=0.00
NUM

Part 5.5
Seasonal Trends



Seasonality

- Refers to cyclic or periodic changes over time.



Monthly average temperature (˚F) in Austin, Texas, 1995 - 1998.

Trends & Seasonality

- Tests for **simple trends** (i.e., monotonic upward or downward trends) not appropriate when there is seasonality (i.e., cyclic changes).
- Use time series plots and LOWESS to investigate possible seasonality.

How to Treat Seasonality

- Several possible options if seasonality exists:
  1. **Take annual leave !** (Most desirable option.)
  2. **Consult statistician** (Let him deal with it.)
  3. **Remove & test for simple trends**
  4. **Do tests designed for seasonal trends.**

Option 3: Remove Seasonality

- For periodic monitoring, determine length of cycle and adjust results using method in EM 1110-1-4014 (Appendix Q).

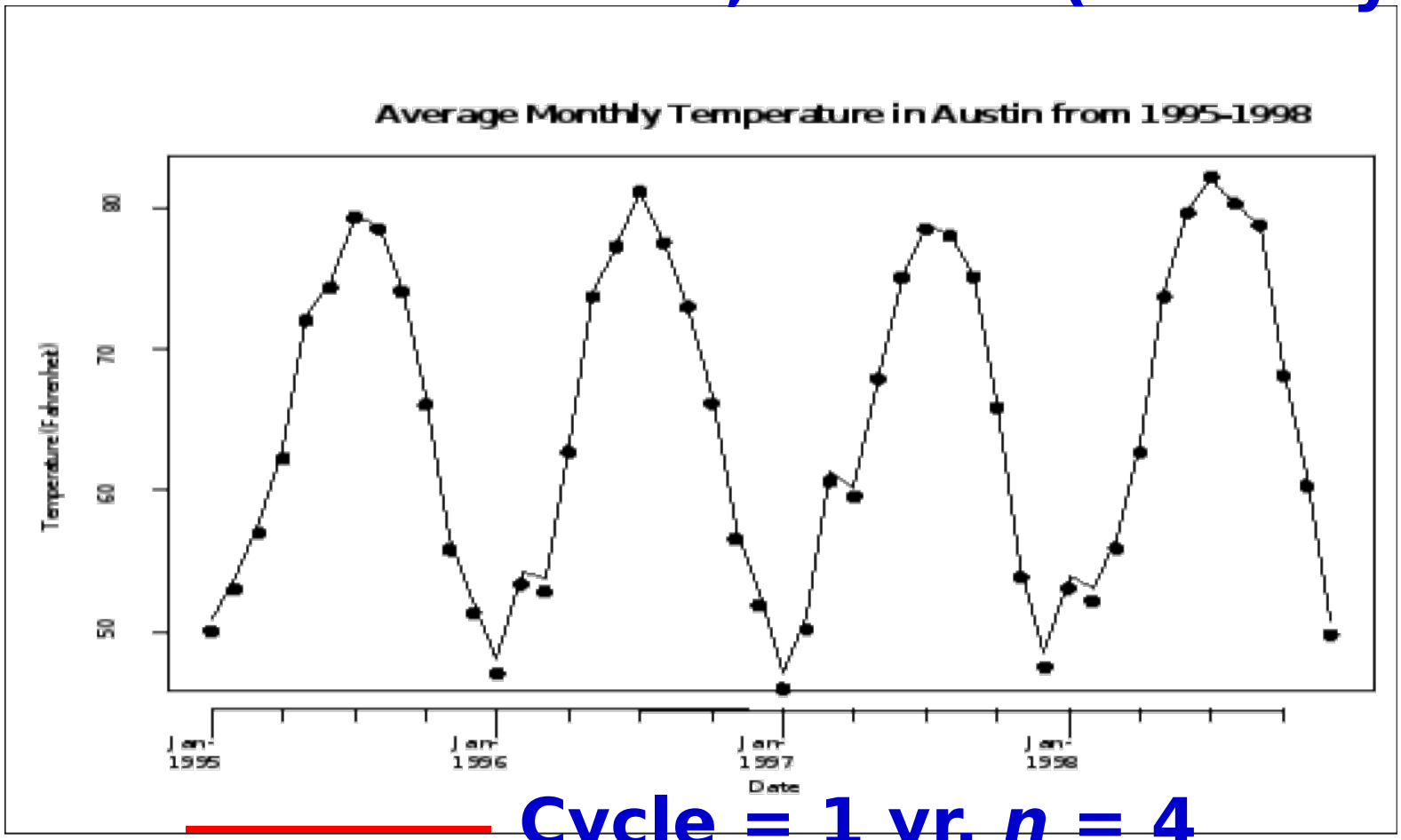
- Definitions:

  - **Cycle** - Length of time pattern repeats or period (e.g., 1 yr). *n* = number of cycles

  - **Season** (VSP) - Length of time between sampling events within each cycle (e.g., one month). *m* = number of seasons

Seasonality

Number of seasons, m = 12 (monthly sam



Cycle = 1 yr, n = 4

Monthly average temperature (˚F) in Austin, Texas, 1995 - 1998.

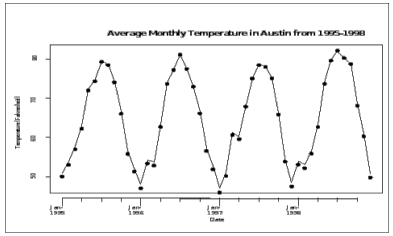
Example

- Cycle = 1 yr; season = 1 mo, $m = 12$, $n = 4$ yr (Monthly sampling for 4 years.)
- Adjust results (concentrations):

  $y_{ij}(adj) = y_{ij} - \bar{y}_i + \bar{y}$

  $\bar{y}_i$ = mean of i^{th} month (season) over $n = 4$ yrs.

  $\bar{y}$ = mean of all y_{ij} ($i = 1, 2,\ldots m$; $j = 1, 2,\ldots n$)
- Test for simple trends using adjusted values.



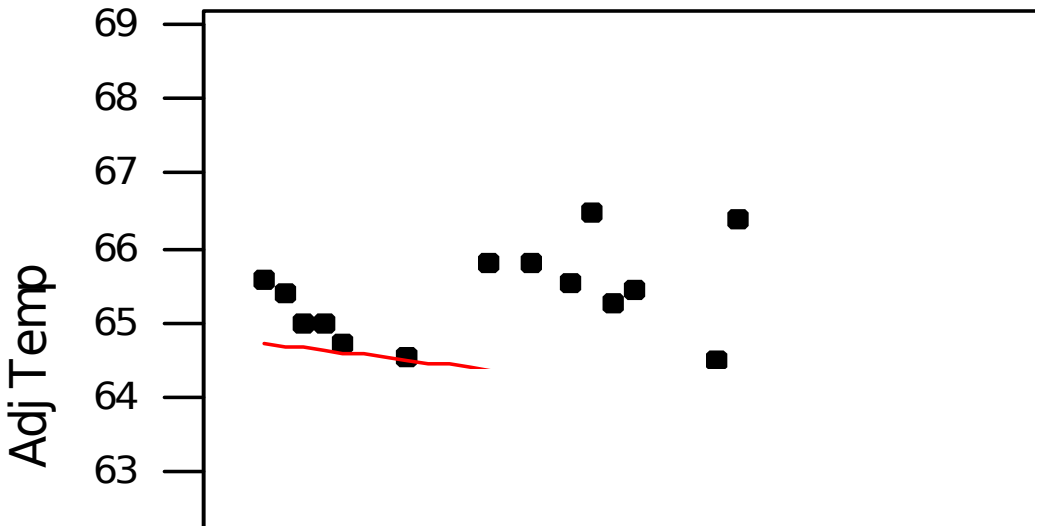
Adjusted Data

No trend

$\tau = 0.12$

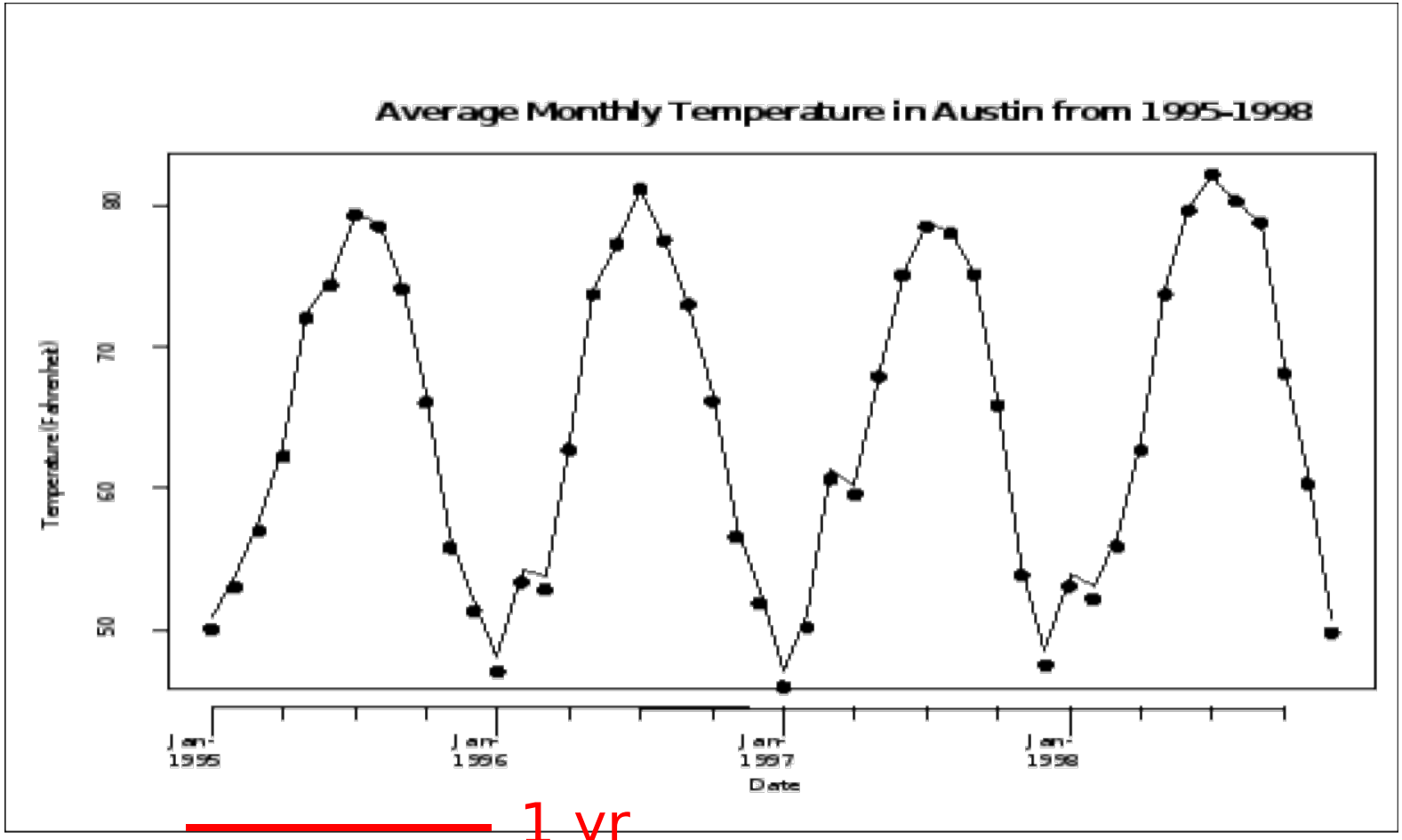
$p = 0.22$

SCATTER PLOT
and LOWESS CURV



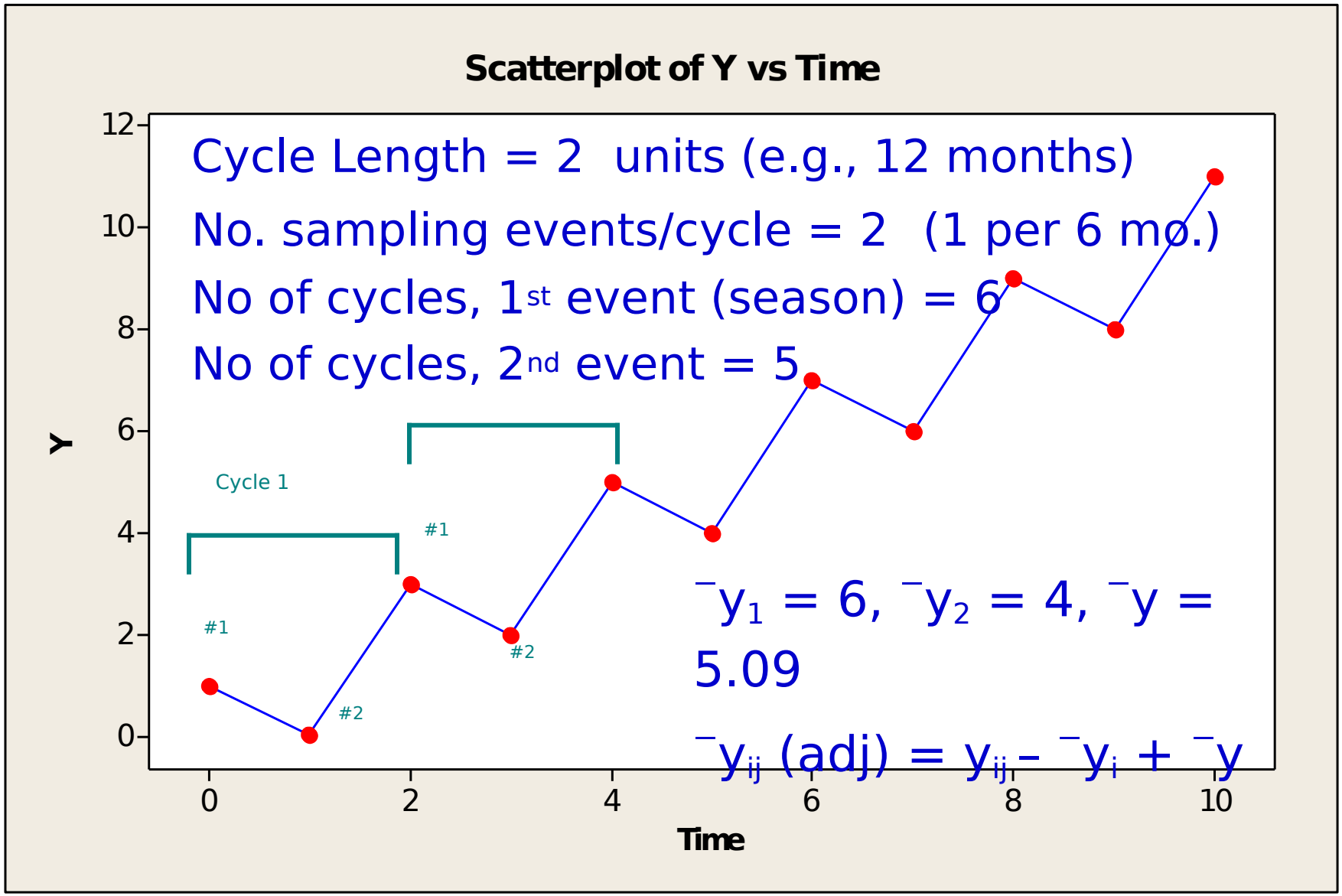
Adjusted monthly average temperature (°F) in Austin, Texas, 1995 -

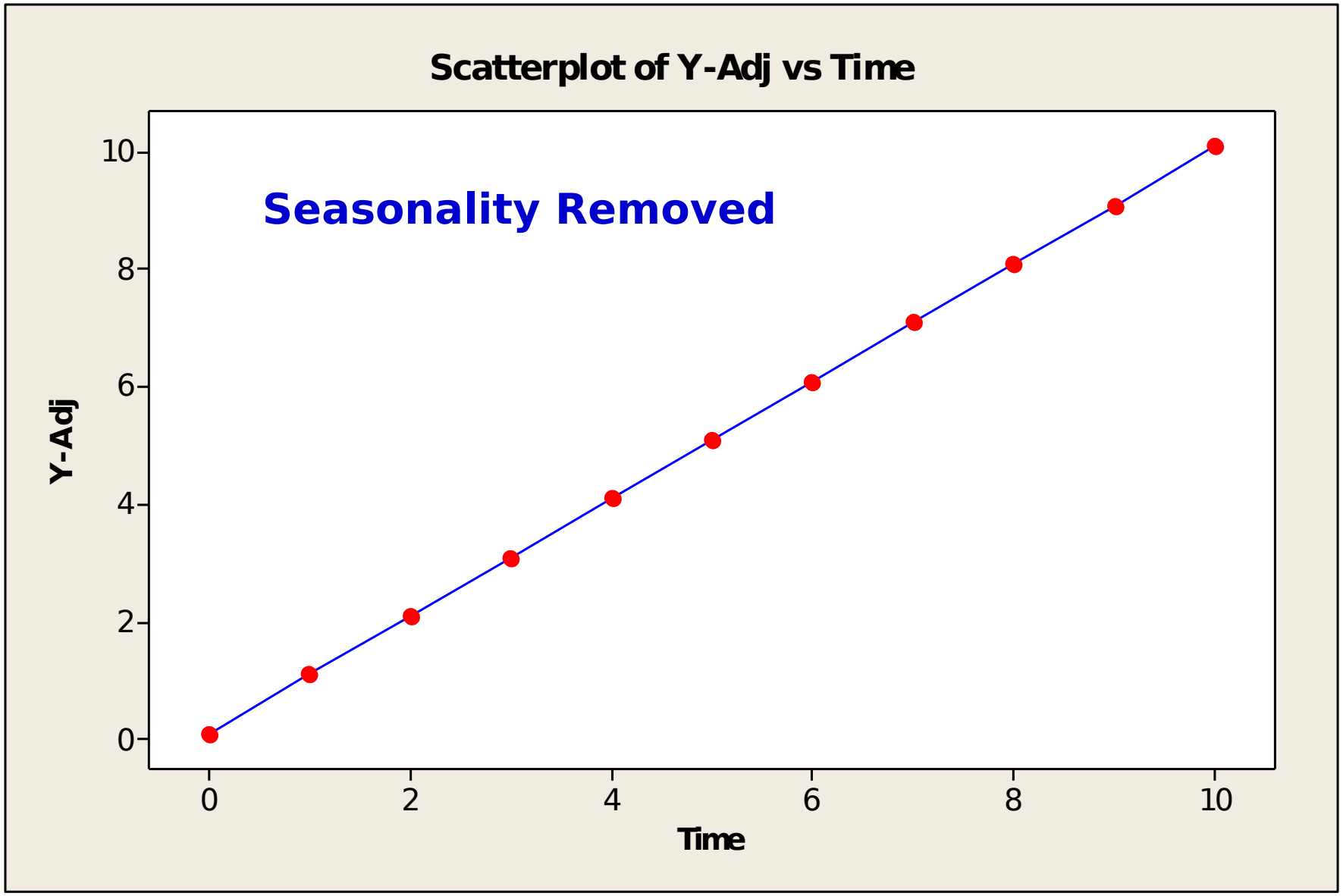
Seasonality with No Upward or Downward Trend



Monthly average temperature (˚F) in Austin, Texas, 1995 - 1998.

Upward Trend + Seasonality




Scatterplot of Y-Adj vs Time
Seasonality Removed
Y-Adj
Time
0
2
4
6
8
10

Option 4: Use Test for Seasonal Data

- **Seasonal Kendall (SK) test**: Extension of Mann-Kendall test for simple trends (available in VSP).
- Example: Cycle = 1 yr. Season = 1 mo. Sampling occurs for $m = 12$ seasons for n yrs (cycles).

  Divide into m (seasonal) data sets:
  $Y_i = \{y_{ij}, j = 1, 2 \ldots n\}$ (Values for i^{th} mo. over n yrs.)
- Calculate S_i and σ_i^2 for each season ($i = 1, 2 \ldots m$).
- Calculate $S = \Sigma_i S_i$, $\sigma_S^2 = \Sigma_i \sigma_i^2$

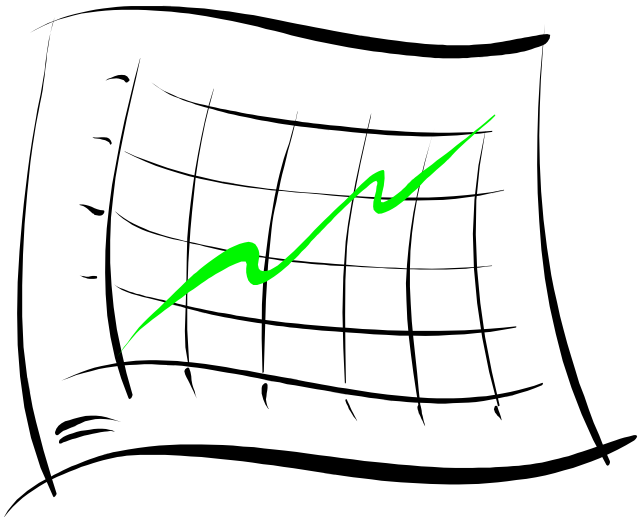
SK Test

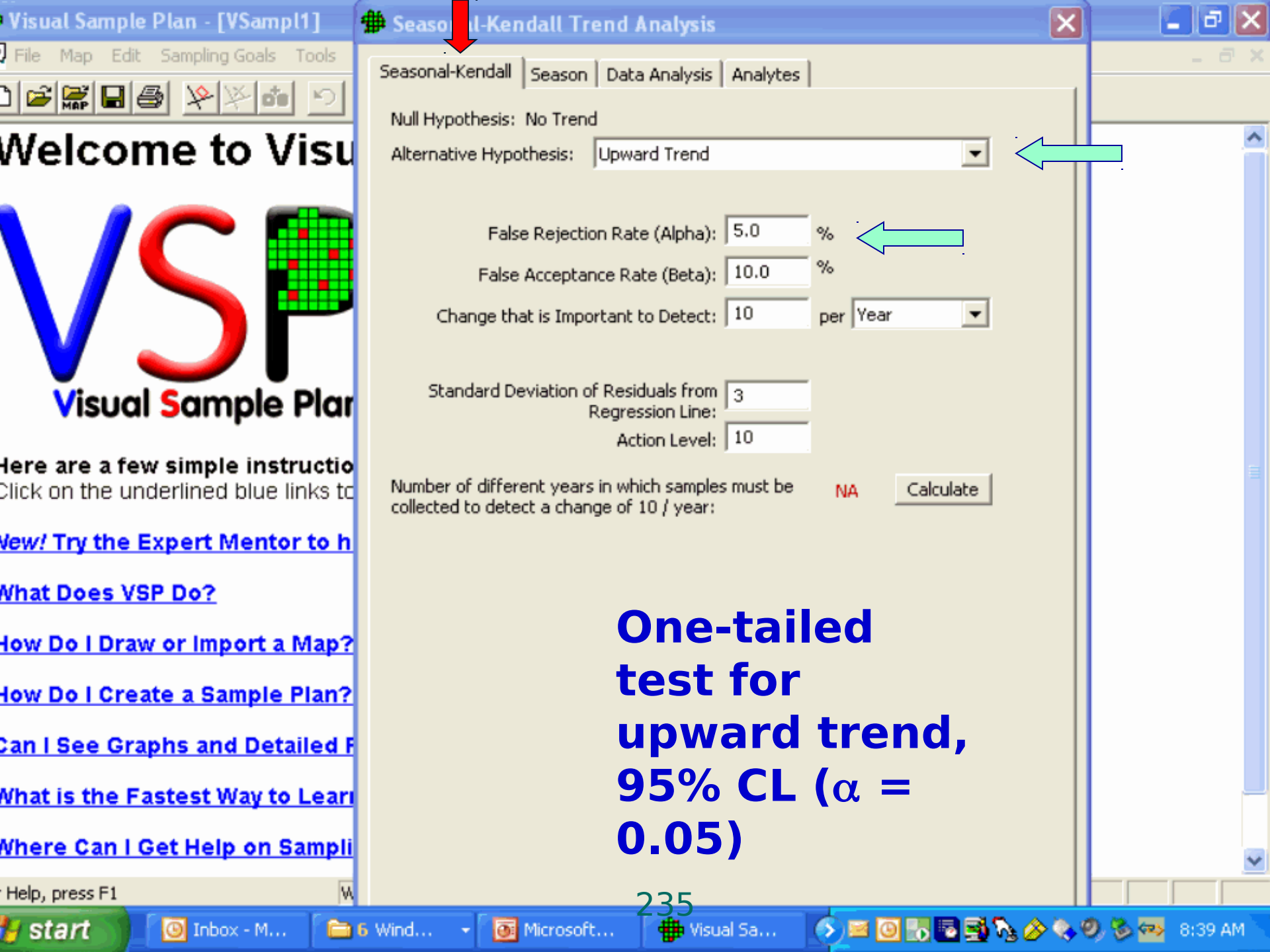
- Calculate $Z = (S \pm 1)/\sigma_S$ and compare to critical value (as for simple trends).
- For example, if $Z > Z_{1-\alpha}$ there is an upward trend for one or more seasons (H_0: No trends).
- **Not appropriate if there are opposing seasonal trends (upward trend in one season but downward in another).**

SK Test for Trends Using VSP

- **Menu**

  Sampling Goals → Detect a Trend → Data not required to be normally distributed → Seasonality

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Seasonal-Kendall Trend Analysis
Seasonal-Kendall
Season
Data Analysis
Analytes
Null Hypothesis: No Trend
Alternative Hypothesis: Upward Trend
False Rejection Rate (Alpha): 5.0 %
False Acceptance Rate (Beta): 10.0 %
Change that is Important to Detect: 10 per Year
Standard Deviation of Residuals from Regression Line: 3
Action Level: 10
Number of different years in which samples must be collected to detect a change of 10 / year:
NA
Calculate
One-tailed test for upward trend, 95% CL (α = 0.05)
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Seasonal-Kenda Trend Analysis

Seasonal-Kendall | Season | Data Analysis | Analytes

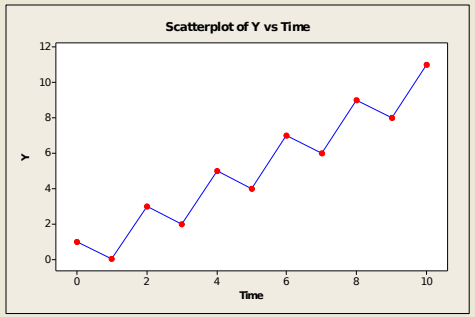
- Month (January, February, ... December)
- Week (Week 1, Week 2, ... Week 52)
- Season (Winter, Spring, Summer, Autumn)
- By Hour (00:XX, 01:XX, ... 23:XX)
- (•) User-Defined Month Seasons
- User-Defined Week Seasons
- User-Defined Hour Seasons

User-Defined Seasons

Period	Season
January	1
February	1
March	1
April	1
May	1
June	1
July	2
August	2
September	2
October	2
November	2
December	2

Edit the entries in the season column, giving each period in a season the same season number. Any season numbers may be used.

Assume two seasons per cycle (to use data on Slide 230).



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Seasonal-Kendall Trend Analysis

Seasonal-Kendall | Season | Data Analysis | Analytes

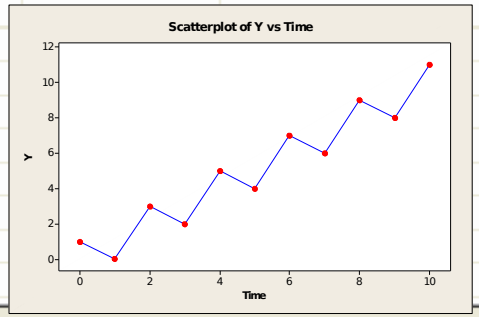
Data Entry | Summary Statistics | Tests | Plots

Enter values by hand, or use the 'Paste' button to paste data from the clipboard, or use the 'Import' button to import data from a file.

Copy | Paste | Import | Data Columns

Date/Time	Value	Location
1/1/2001	1	
7/1/2001	0	
1/1/2002	3	
7/1/2002	2	
1/1/2003	5	
7/1/2003	4	
1/1/2004	7	
7/1/2004	6	
1/1/2005	9	
7/1/2005	8	
1/1/2006	11	

Data on Slide 230



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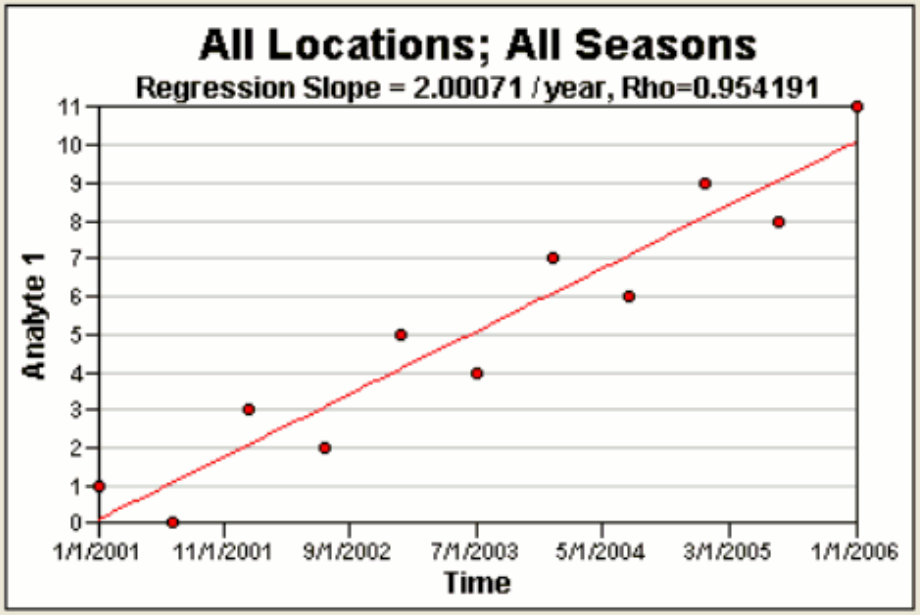
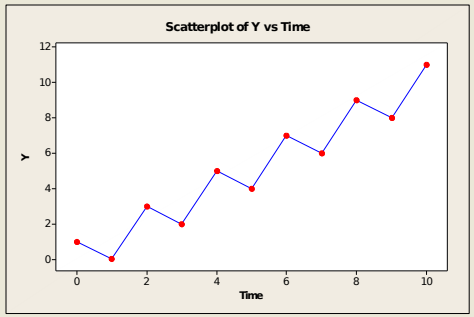
Data Entry | Summary Statistics | Tests | Plots

Time vs. Data | Values | Residuals | All Locations | All Seasons





All data.

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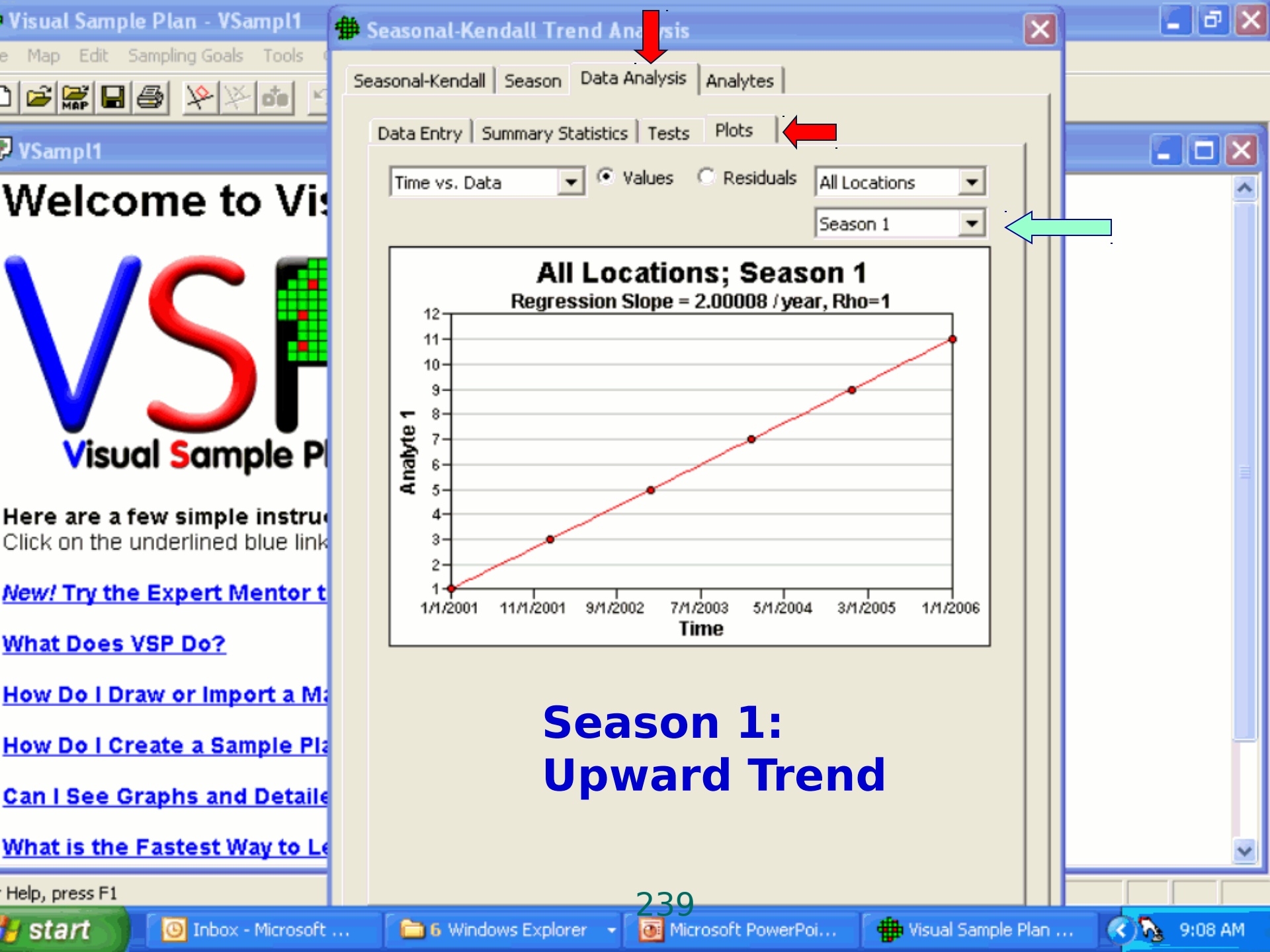
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Tests
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Time vs. Data
Values
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All Locations
Season 1
All Locations; Season 1
Regression Slope = 2.00008 /year, Rho=1
Analyte 1
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11
10
9
8
7
6
5
4
3
2
1
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11/1/2001
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7/1/2003
5/1/2004
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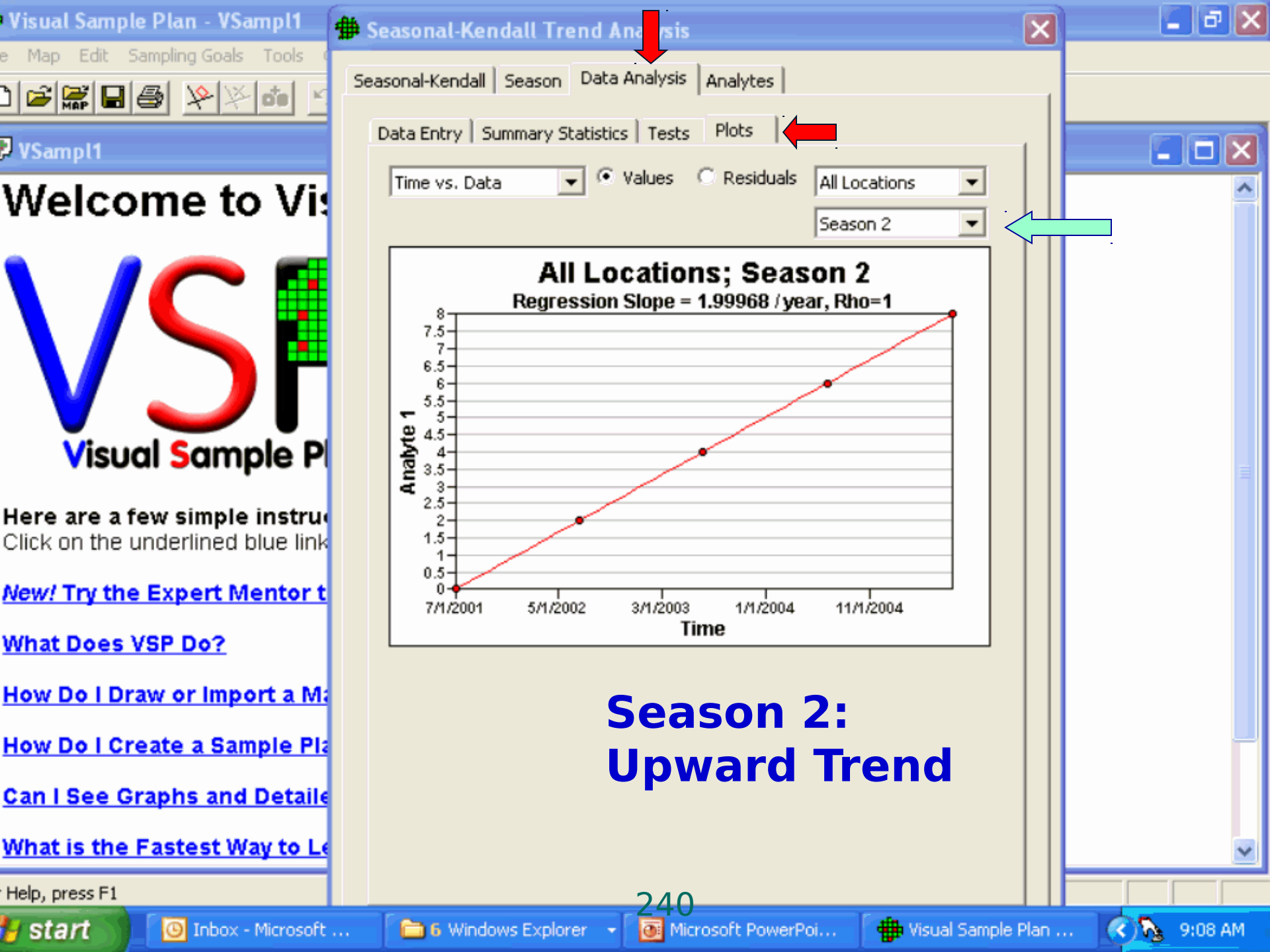
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Seasonal-Kendall
Season
Data Analysis
Analytes
Data Entry
Summary Statistics
Tests
Plots
Time vs. Data
Values
Residuals
All Locations
Season 2
All Locations; Season 2
Regression Slope = 1.99968 /year, Rho=1
Analyte 1
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
7/1/2001
5/1/2002
3/1/2003
1/1/2004
11/1/2004
Time
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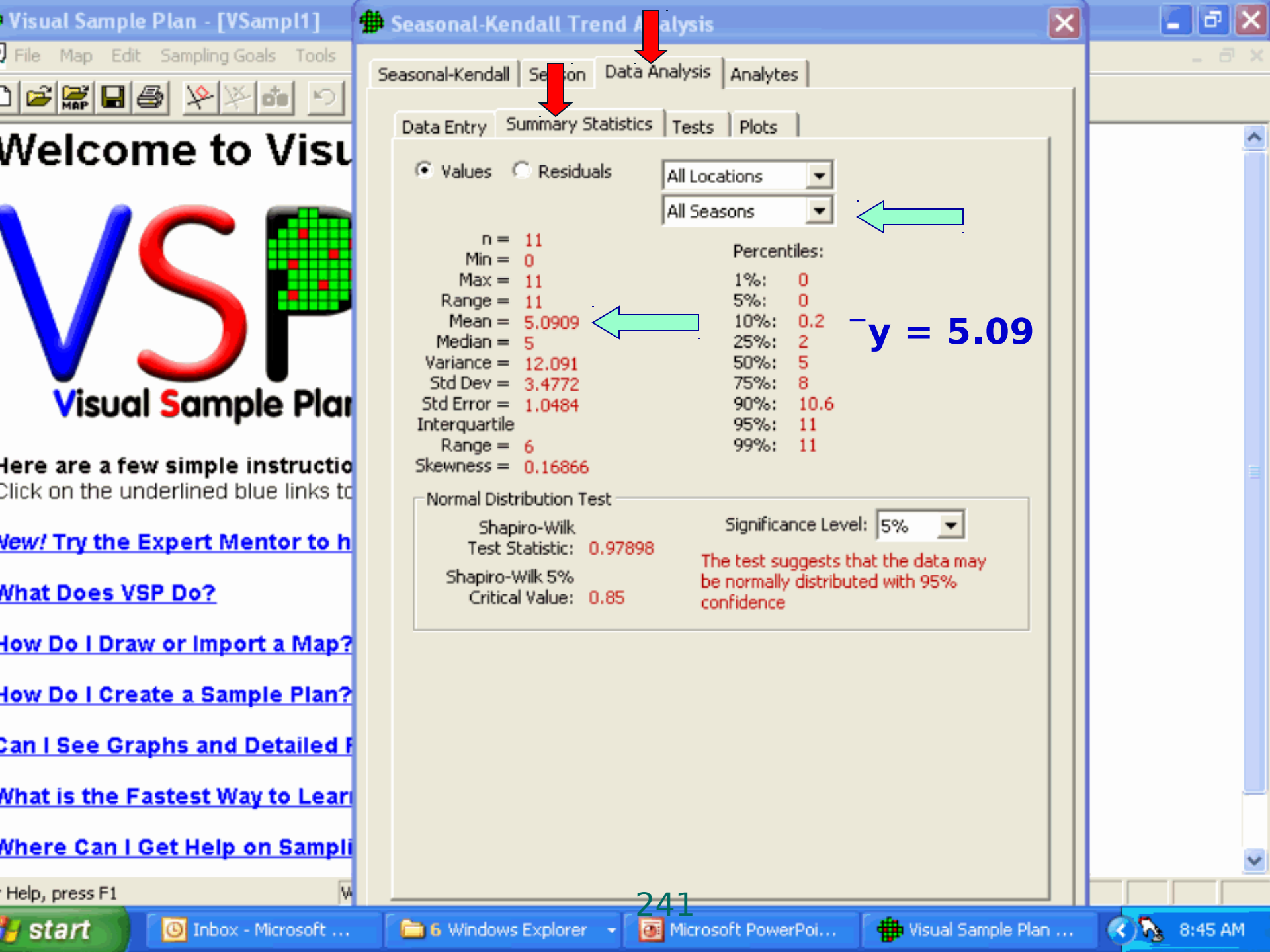
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Seasonal-Kendall Trend Analysis
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Summary Statistics
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Plots
Values
Residuals
All Locations
All Seasons
n = 11
Min = 0
Max = 11
Range = 11
Mean = 5.0909
Median = 5
Variance = 12.091
Std Dev = 3.4772
Std Error = 1.0484
Interquartile Range = 6
Skewness = 0.16866
Percentiles:
1%: 0
5%: 0
10%: 0.2
25%: 2
50%: 5
75%: 8
90%: 10.6
95%: 11
99%: 11
$\bar{y} = 5.09$
Normal Distribution Test
Shapiro-Wilk Test Statistic: 0.97898
Shapiro-Wilk 5% Critical Value: 0.85
Significance Level: 5%
The test suggests that the data may be normally distributed with 95% confidence
start
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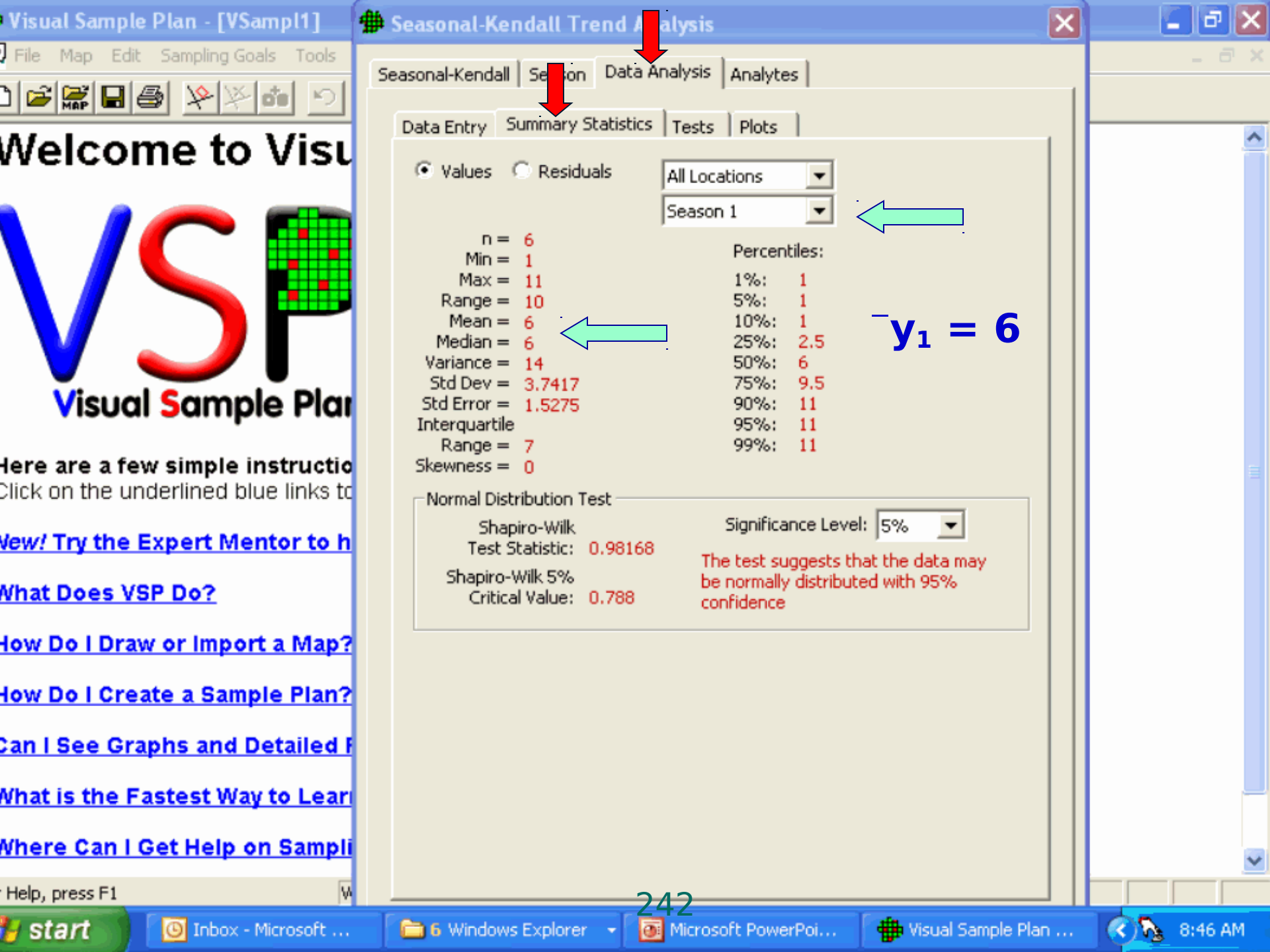
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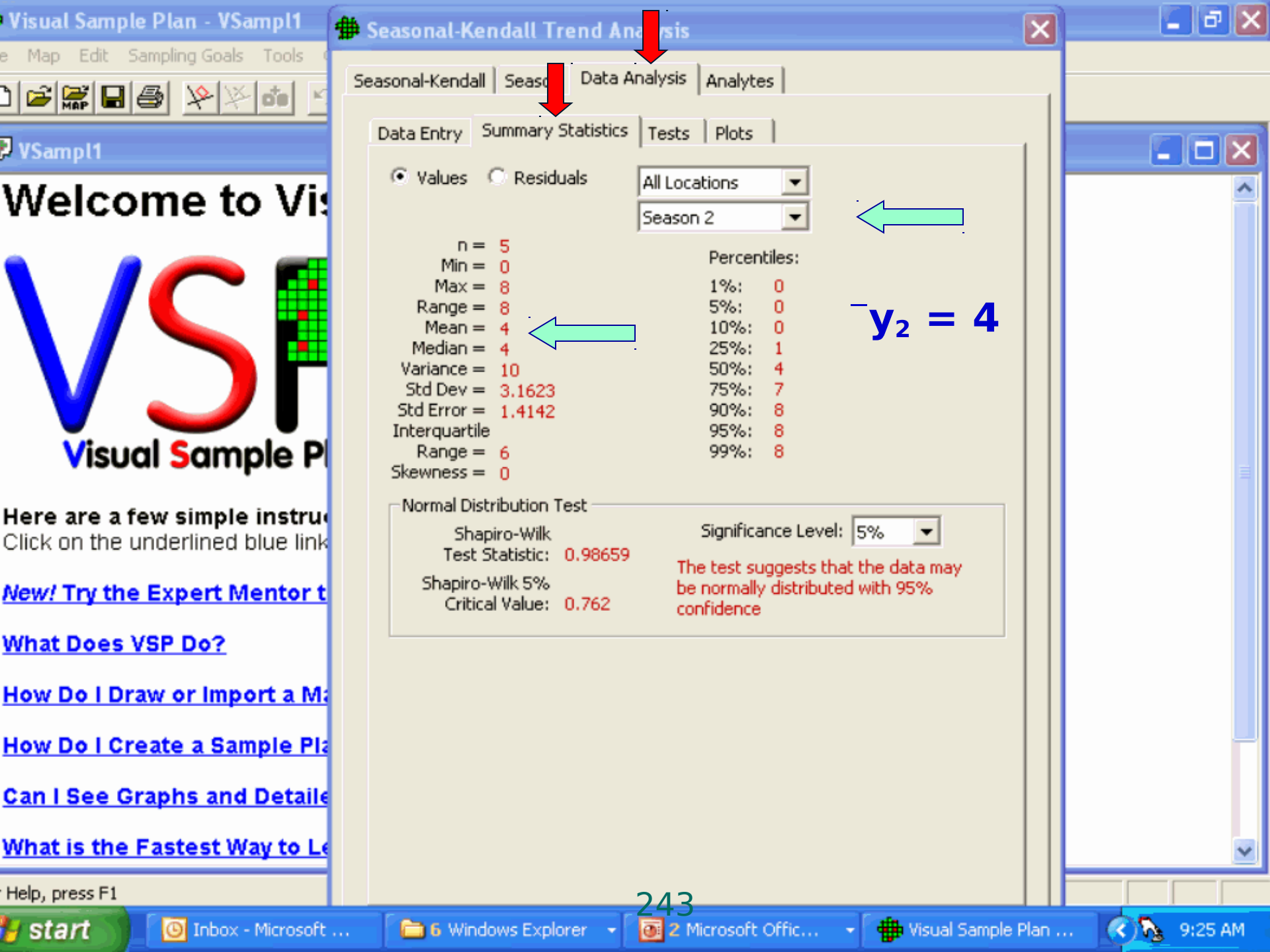
Plots
Values
Residuals
All Locations
Season 1
n = 6
Min = 1
Max = 11
Range = 10
Mean = 6
Median = 6
Variance = 14
Std Dev = 3.7417
Std Error = 1.5275
Interquartile Range = 7
Skewness = 0
Percentiles:
1%: 1
5%: 1
10%: 1
25%: 2.5
50%: 6
75%: 9.5
90%: 11
95%: 11
99%: 11
$\bar{y}_1 = 6$
Normal Distribution Test
Shapiro-Wilk Test Statistic: 0.98168
Shapiro-Wilk 5% Critical Value: 0.788
Significance Level: 5%
The test suggests that the data may be normally distributed with 95% confidence
start
Inbox - Microsoft ...
6 Windows Explorer
Microsoft PowerPoi...
Visual Sample Plan ...
8:46 AM


Visual Sample Plan - VSampl1
Map Edit Sampling Goals Tools
VSampl1
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What Does VSP Do?
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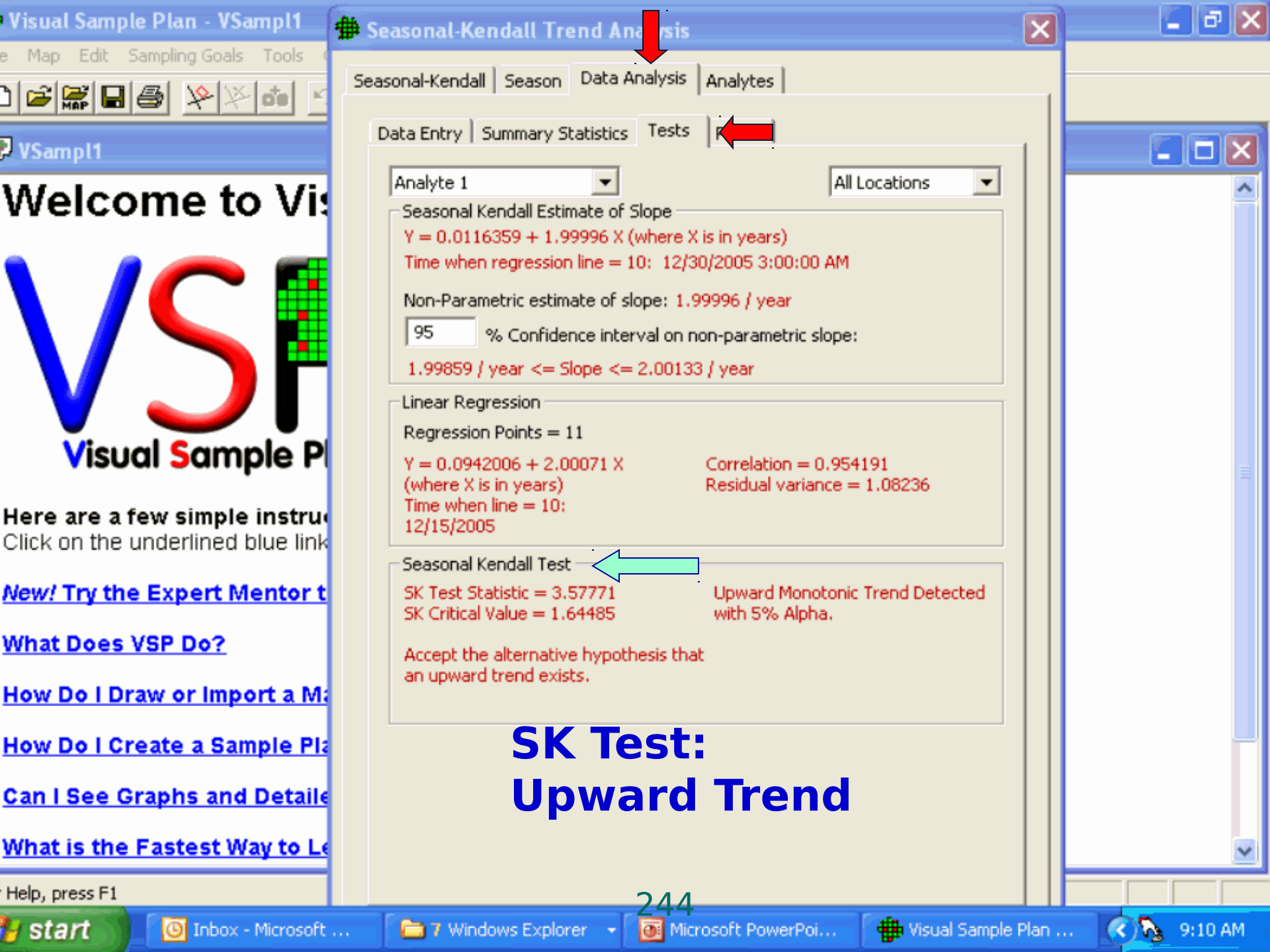
Seasonal-Kendall Trend Analysis
Seasonal-Kendall
Seasc
Data Analysis
Analytes
Data Entry
Summary Statistics
Tests
Plots
Values
Residuals
All Locations
Season 2
n = 5
Min = 0
Max = 8
Range = 8
Mean = 4
Median = 4
Variance = 10
Std Dev = 3.1623
Std Error = 1.4142
Interquartile Range = 6
Skewness = 0
Percentiles:
1%: 0
5%: 0
10%: 0
25%: 1
50%: 4
75%: 7
90%: 8
95%: 8
99%: 8
$\bar{y}_2 = 4$
Normal Distribution Test
Shapiro-Wilk Test Statistic: 0.98659
Shapiro-Wilk 5% Critical Value: 0.762
Significance Level: 5%
The test suggests that the data may be normally distributed with 95% confidence
start
Inbox - Microsoft ...
6 Windows Explorer
2 Microsoft Offic...
Visual Sample Plan ...
9:25 AM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Help, press F1
Seasonal-Kendall Trend Analysis
Seasonal-Kendall
Season
Data Analysis
Analytes
Data Entry
Summary Statistics
Tests
Analyte 1
All Locations
Seasonal Kendall Estimate of Slope
Y = 0.0116359 + 1.99996 X (where X is in years)
Time when regression line = 10: 12/30/2005 3:00:00 AM
Non-Parametric estimate of slope: 1.99996 / year
95
% Confidence interval on non-parametric slope:
1.99859 / year <= Slope <= 2.00133 / year
Linear Regression
Regression Points = 11
Y = 0.0942006 + 2.00071 X
(where X is in years)
Time when line = 10:
12/15/2005
Correlation = 0.954191
Residual variance = 1.08236
Seasonal Kendall Test
SK Test Statistic = 3.57771
SK Critical Value = 1.64485
Upward Monotonic Trend Detected with 5% Alpha.
Accept the alternative hypothesis that an upward trend exists.
start
Inbox - Microsoft ...
7 Windows Explorer
Microsoft PowerPoi...
Visual Sample Plan ...
9:10 AM

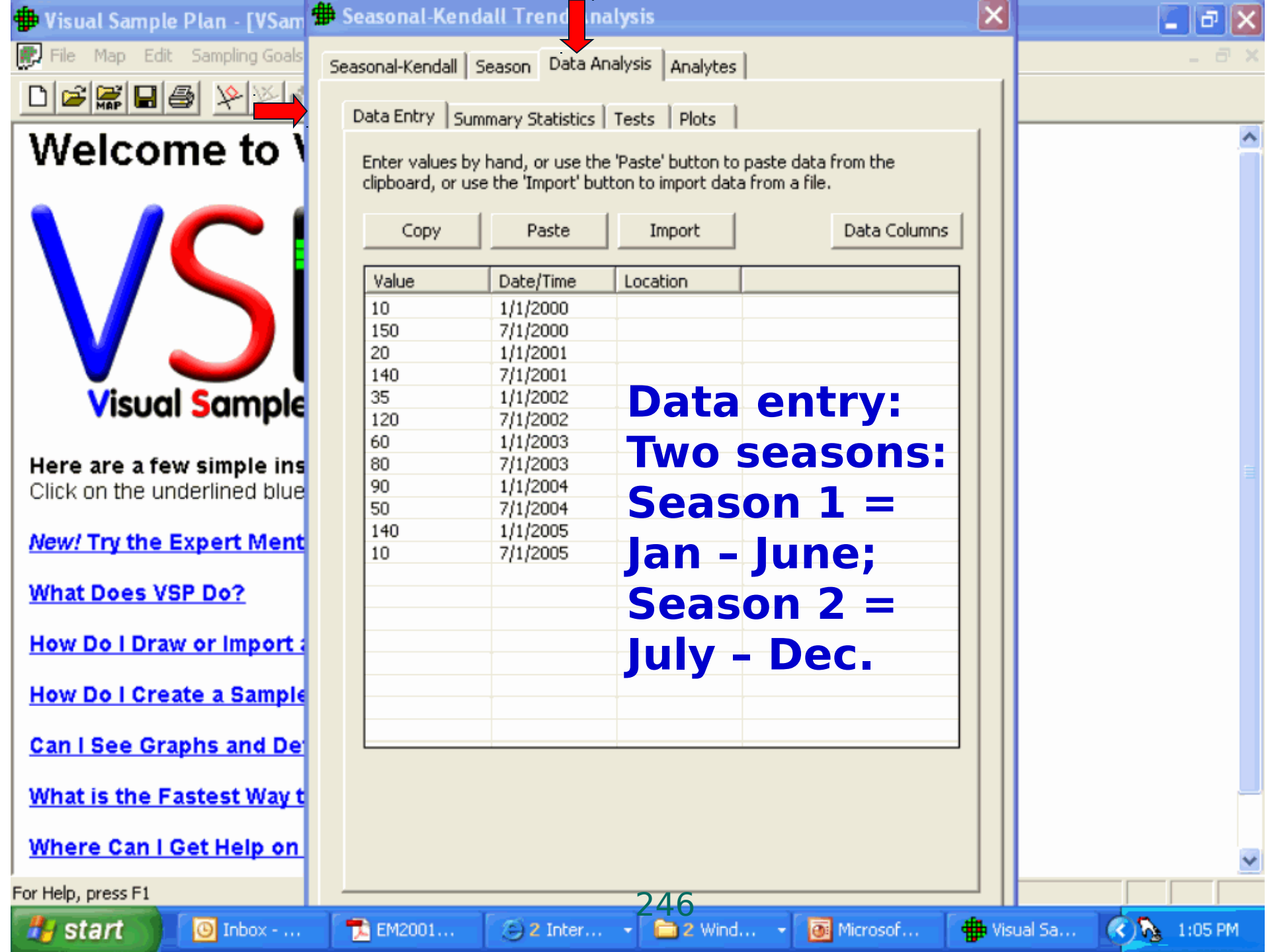
SK Test:
Upward Trend

SK Test and Mixed Seasonal Trends

- What happens when seasonal trends are in opposite directions?

SK will fail to detect a trend !

- Data for each season need be separately evaluated for trends to ensure all trends are in same direction.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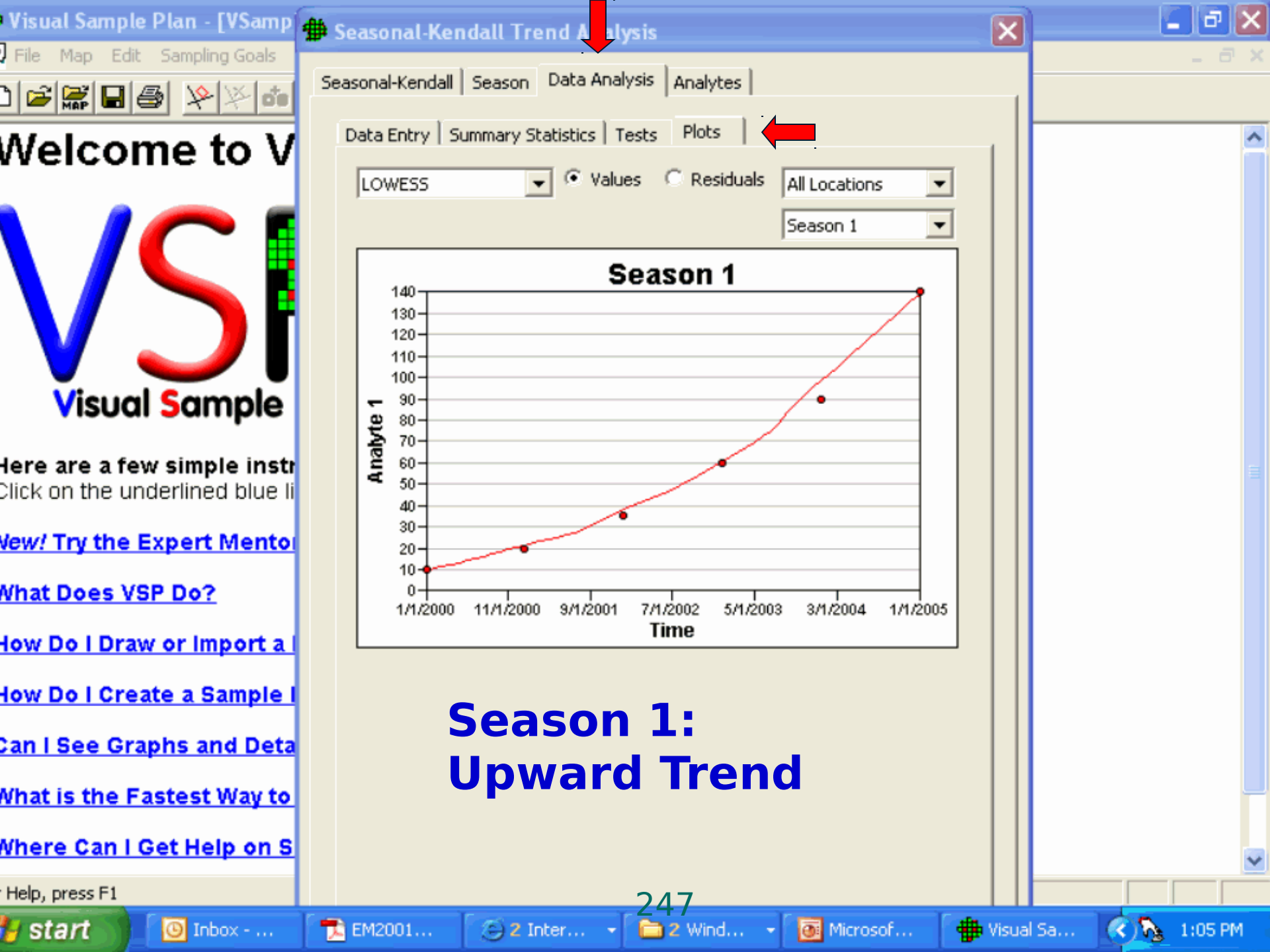
For Help, press F1
Seasonal-Kendall Trend Analysis
Seasonal-Kendall
Season
Data Analysis
Analytes
Data Entry
Summary Statistics
Tests
Plots
Enter values by hand, or use the 'Paste' button to paste data from the clipboard, or use the 'Import' button to import data from a file.
Copy
Paste
Import
Data Columns
Value
Date/Time
Location
10 1/1/2000
150 7/1/2000
20 1/1/2001
140 7/1/2001
35 1/1/2002
120 7/1/2002
60 1/1/2003
80 7/1/2003
90 1/1/2004
50 7/1/2004
140 1/1/2005
10 7/1/2005
Data entry:
Two seasons:
Season 1 =
Jan – June;
Season 2 =
July – Dec.
start
Inbox - ...
EM2001...
2 Inter...
2 Wind...
Microsof...
Visual Sa...
1:05 PM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Seasonal-Kendall Trend Analysis
Seasonal-Kendall
Season
Data Analysis
Analytes
Data Entry
Summary Statistics
Tests
Plots
LOWESS
Values
Residuals
All Locations
Season 1
Season 1
Analyte 1
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1/1/2000
11/1/2000
9/1/2001
7/1/2002
5/1/2003
3/1/2004
1/1/2005
Time
Season 1:
Upward Trend
start
Inbox - ...
EM2001...
2 Inter...
2 Wind...
Microsof...
Visual Sa...
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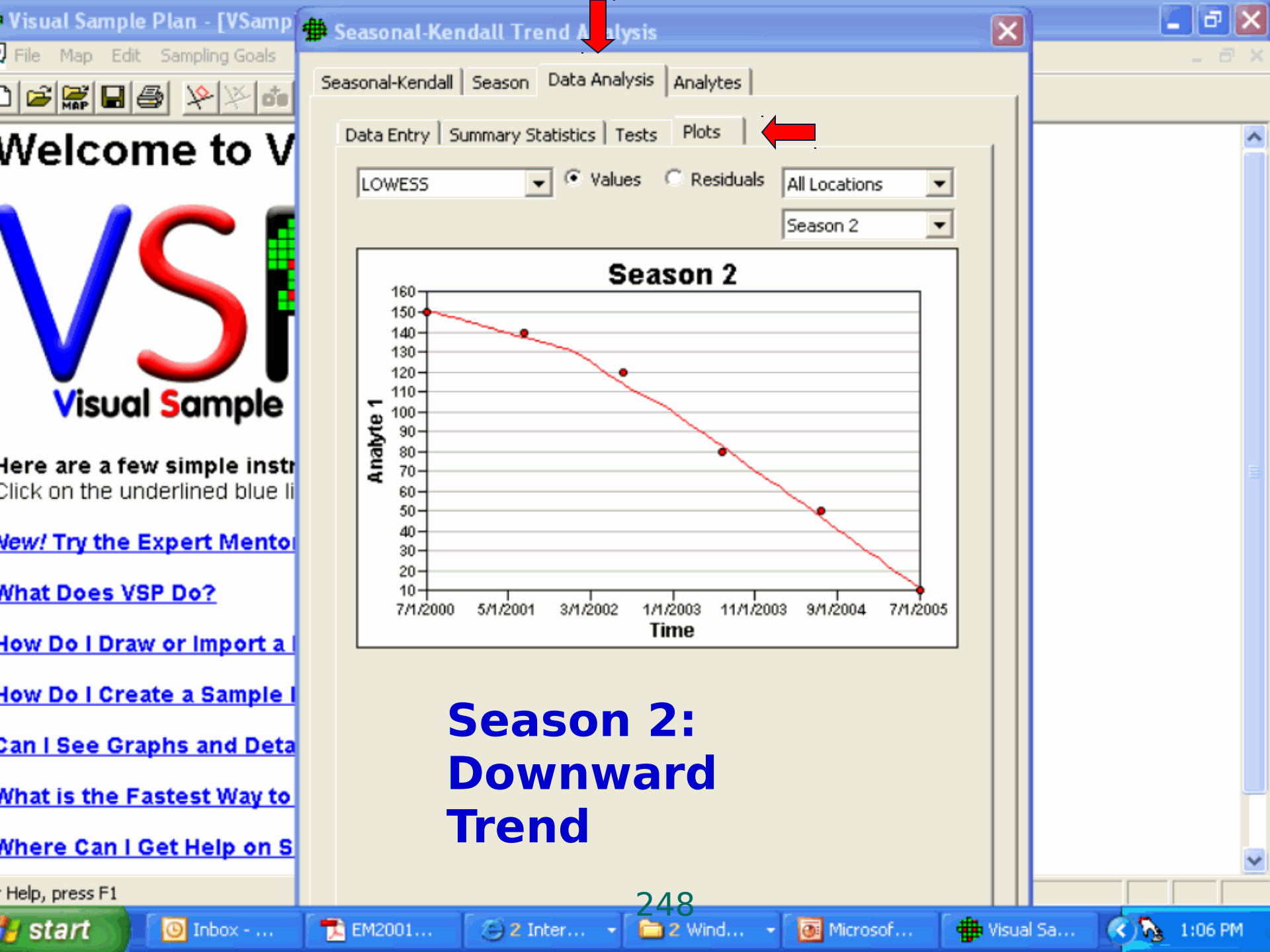
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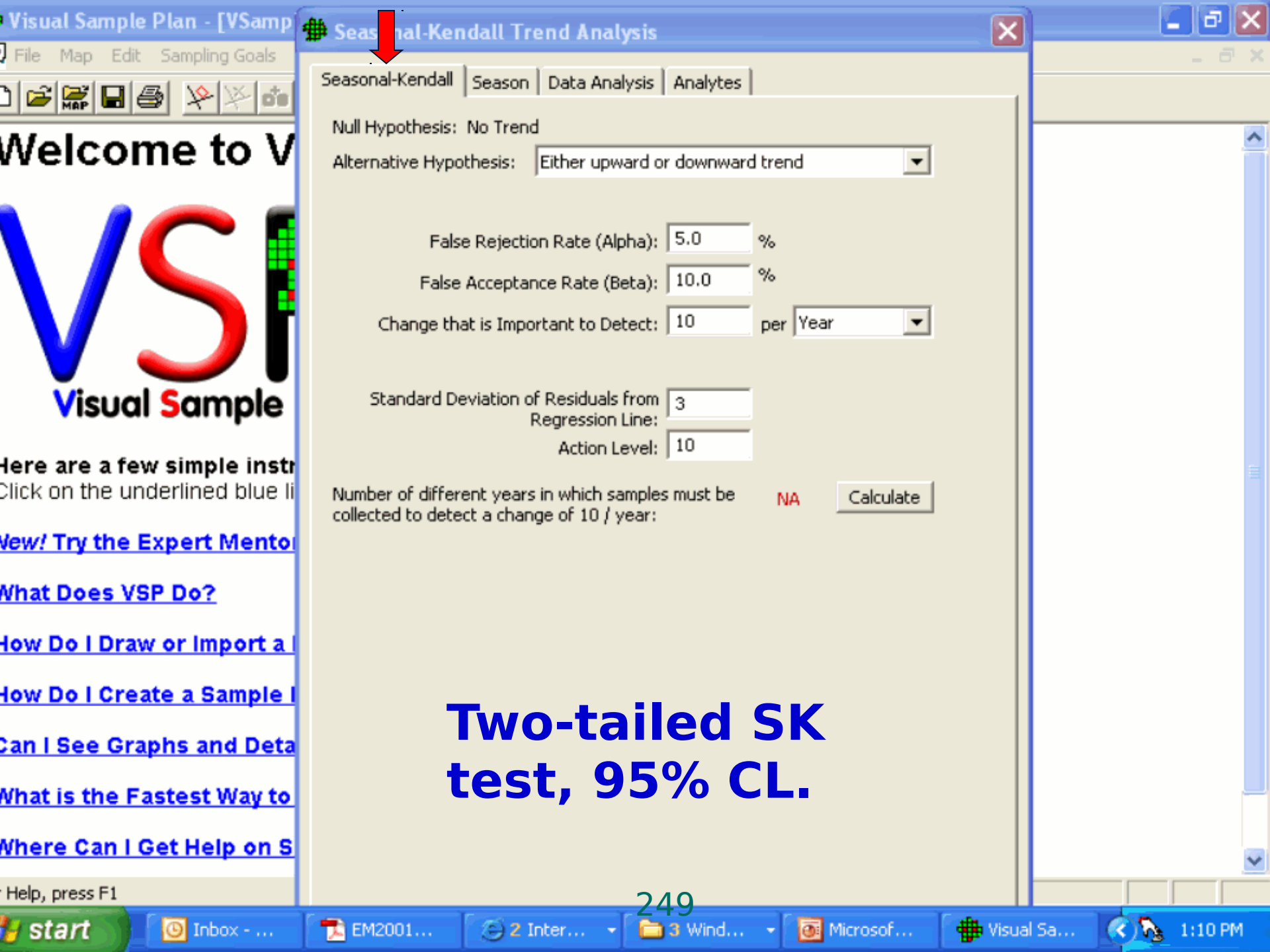
Seasonal-Kendall Trend Analysis
Seasonal-Kendall
Season
Data Analysis
Analytes
Data Entry
Summary Statistics
Tests
Plots
LOWESS
Values
Residuals
All Locations
Season 2
Season 2
Analyte 1
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
7/1/2000
5/1/2001
3/1/2002
1/1/2003
11/1/2003
9/1/2004
7/1/2005
Time
Season 2: Downward Trend
248
start
Inbox - ...
EM2001...
2 Inter...
2 Wind...
Microsof...
Visual Sa...
1:06 PM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File Map Edit Sampling Goals
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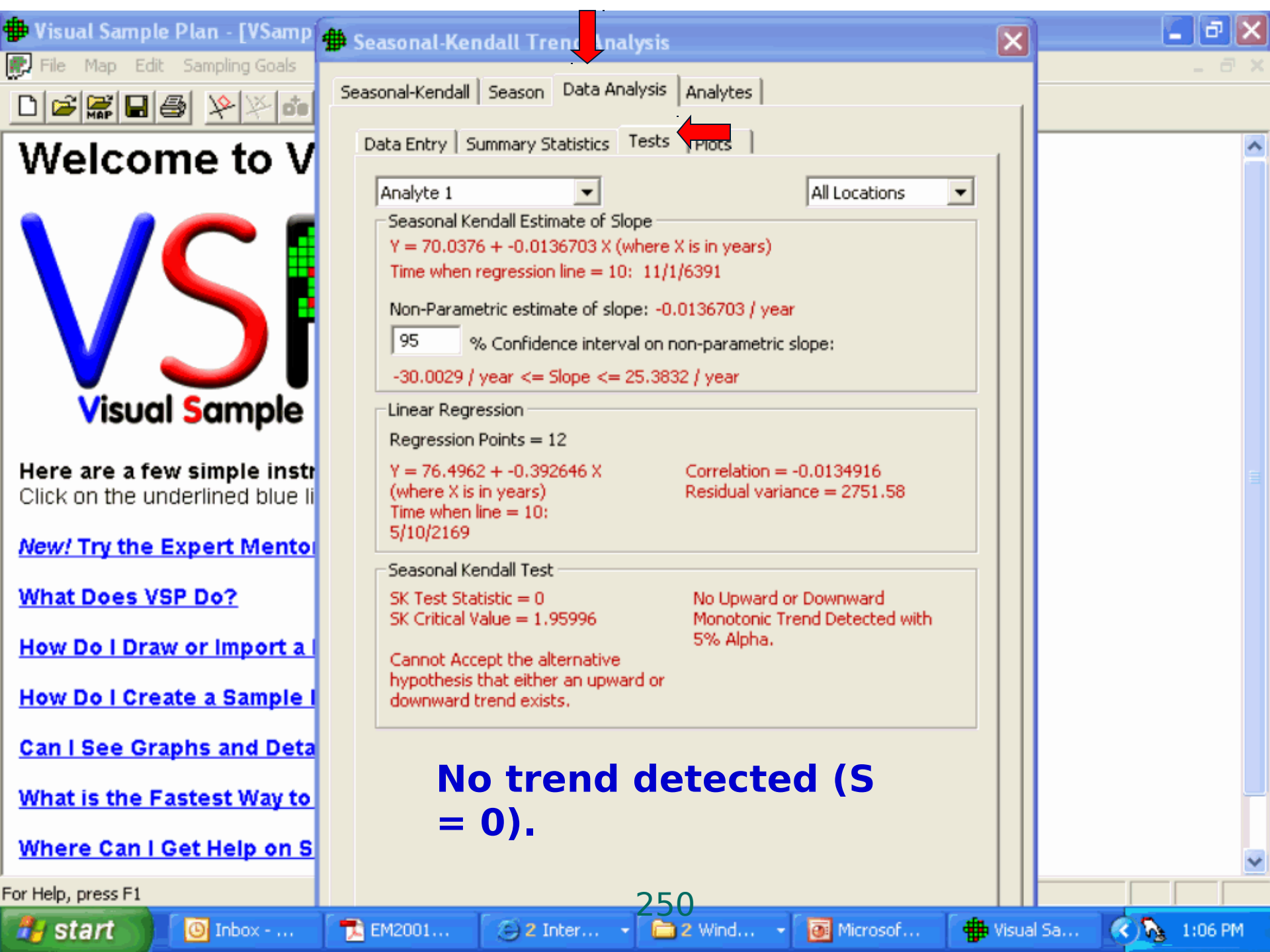
How Do I Create a Sample
Can I See Graphs and Deta
What is the Fastest Way to
Where Can I Get Help on S
Help, press F1
Seasonal-Kendall Trend Analysis
Seasonal-Kendall
Season
Data Analysis
Analytes
Null Hypothesis: No Trend
Alternative Hypothesis:
Either upward or downward trend
False Rejection Rate (Alpha):
5.0
%
False Acceptance Rate (Beta):
10.0
%
Change that is Important to Detect:
10
per
Year
Standard Deviation of Residuals from Regression Line:
3
Action Level:
10
Number of different years in which samples must be collected to detect a change of 10 / year:
NA
Calculate
Two-tailed SK test, 95% CL.
start
Inbox - ...
EM2001...
2 Inter...
3 Wind...
Microsof...
Visual Sa...
1:10 PM


Visual Sample Plan - [VSamp
File Map Edit Sampling Goals
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How Do I Draw or Import a
How Do I Create a Sample
Can I See Graphs and Deta
What is the Fastest Way to
Where Can I Get Help on S
For Help, press F1
Seasonal-Kendall Trend Analysis
Seasonal-Kendall
Season
Data Analysis
Analytes
Data Entry
Summary Statistics
Tests
Plots
Analyte 1
All Locations
Seasonal Kendall Estimate of Slope
Y = 70.0376 + -0.0136703 X (where X is in years)
Time when regression line = 10: 11/1/6391
Non-Parametric estimate of slope: -0.0136703 / year
95
% Confidence interval on non-parametric slope:
-30.0029 / year <= Slope <= 25.3832 / year
Linear Regression
Regression Points = 12
Y = 76.4962 + -0.392646 X
(where X is in years)
Time when line = 10:
5/10/2169
Correlation = -0.0134916
Residual variance = 2751.58
Seasonal Kendall Test
SK Test Statistic = 0
SK Critical Value = 1.95996
No Upward or Downward
Monotonic Trend Detected with
5% Alpha.
Cannot Accept the alternative
hypothesis that either an upward or
downward trend exists.
No trend detected (S = 0).
start
Inbox - ...
EM2001...
2 Inter...
2 Wind...
Microsof...
Visual Sa...
1:06 PM

Questions

- **Contact Information**

402-697-2567

thomas.georgian@usace.army.mil

Monday – Thursday, 6:00 a.m. – 4:30 p.m.